neutral
independent
non-profit institute

IKT - Institute for Underground Infrastructure

2008-2010

RESEARCH & TESTING

research | testing | consulting

neutral
independent
non-profit institute
IKT
approved
client:
norm:
report no.:
date:
www.ikt.de

neutral
independent
non-profit institute
IKT
Product-Test
VERY GOOD
Contractor:
Network Operators and Suppliers
Download Test Report:
www.ikt.de

contents:

Results with practical benefits

Not only in Germany, but also in a large number of other countries, operators invest large amounts every year in public drain and sewer systems alone. Numerous suppliers of the most diverse range of processes and products all compete for this custom. Competition is tough, and not a few high-gloss brochures promise much more than is really possible.

The clients have become increasingly critical, however. More than ever before, they find themselves confronted with decisive questions: How do I locate the right product, in view of the large selection of suppliers and their contradictory arguments? How can I know which products really do what their salesmen promise? Reliable technical information - hard facts, not advertising slogans - are needed to permit correct decisions.

Exactly here is where the IKT can help, with its practically orientated tests. As an impartial, independent and non-profit-making research and test institution, we regularly test building products for drain and sewer systems to their utmost. The target is that of supplying reliable and well-founded aids to decision-making.

Unique in this context is our combination of science and practice. As a research institution, the IKT is constantly generating new knowledge. Research topics are defined „on site", not at the conference table. Close contact is maintained with the system operators to ensure exactly this. They, ultimately, provide the impulses for IKT projects. And new research data is incorporated immediately into the work of the three IKT test bodies, viz.:

- the DIBt-recognized Building-Products Inspection Body
- the state-accredited Test Body for Flow Measurements and
- the DIBt-appointed Test Body for Water-Permeable Surfacings

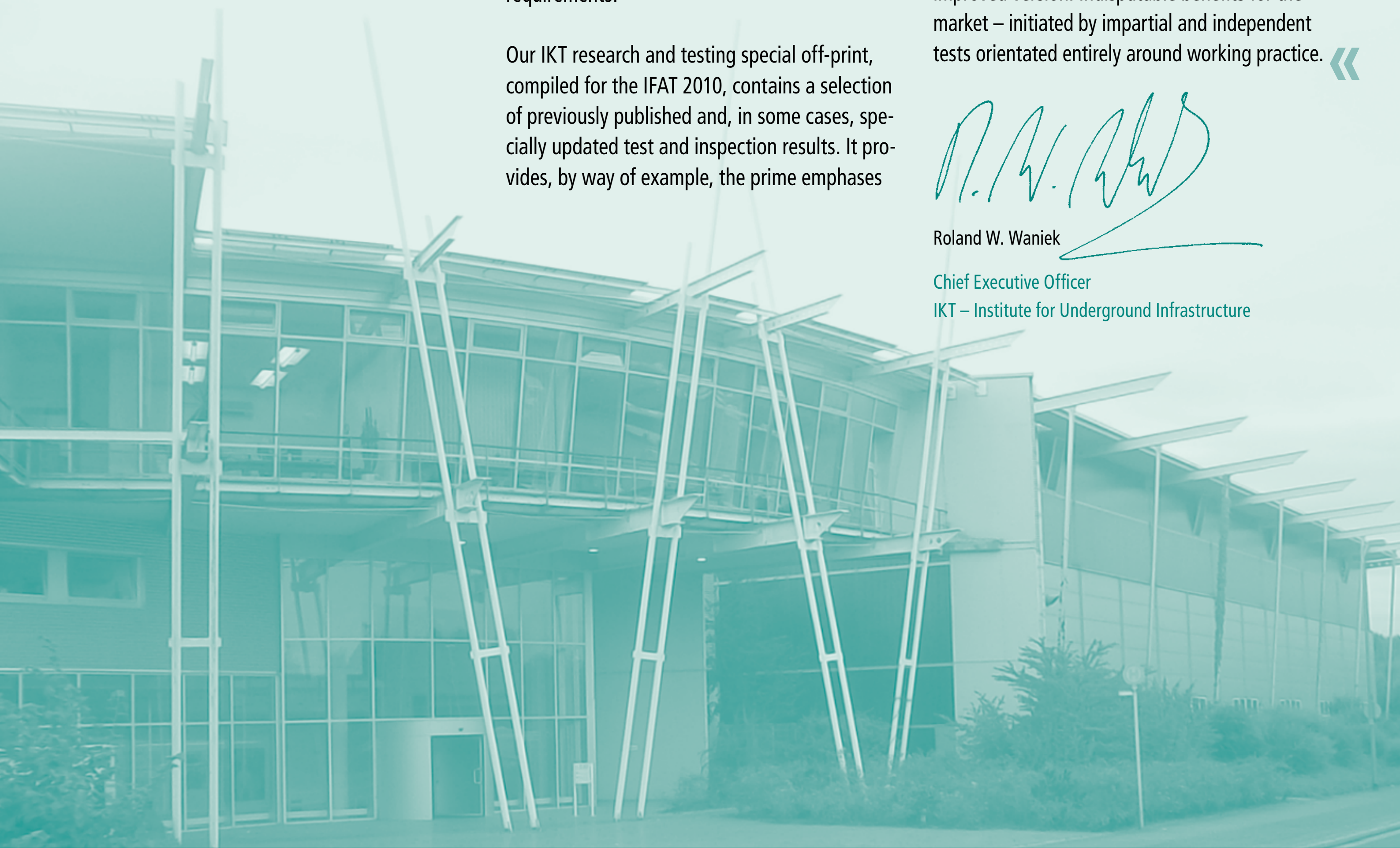
In its Product Tests, the IKT goes one step further: every comparative test is supported by a group of system operators. Decisions concerning test contents, test procedures and test evaluations are made jointly by the group in a working committee. This ensures that the tests are closely practically orientated and that the test results are evaluated in line with the operators' quality requirements.

Our IKT research and testing special off-print, compiled for the IFAT 2010, contains a selection of previously published and, in some cases, specially updated test and inspection results. It provides, by way of example, the prime emphases and the bandwidth of the examinations and product tests performed in recent years.

As a visitor to the IFAT, you yourself have the opportunity of observing the results of the IKT's work while touring the exhibition; many of the products tested have been revised by their manufacturers and are now offered in an improved version. Indisputable benefits for the market – initiated by impartial and independent tests orientated entirely around working practice.

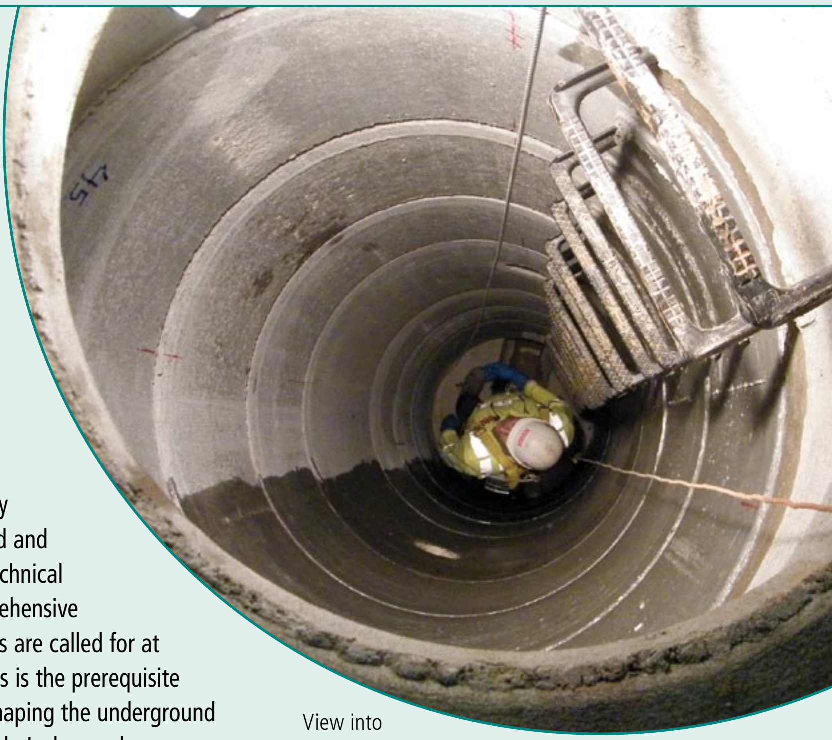
Roland W. Waniek

Chief Executive Officer
IKT – Institute for Underground Infrastructure



Content

Current focus of action and perspectives



View into
6 meter deep test manhole

What is the meaning of underground infrastructure? Which requirements are to be observed? What do participants have to do? Which technical solutions are suitable? These are some of the questions that the IKT - Institute for Underground Infrastructure jointly pursues with more than 150 members of both IKT-Association of Network Operators and of Industry and Service in research, testing, consultancy and product test projects. Focal points currently lie in sewer and pipeline construction.

Underground assets

The replacement value of public underground infrastructure in Germany, the supply utilities via sewage systems up to the traffic tunnels, amounts to more than 600 billion Euros. Approximately 550 billion Euros more are spent on the supply and disposal networks for gas, water, and sewage, with network lengths much more than 1 million kilometres. The largest share is taken by the sewage system with approx. 330 billion Euros replacement value, i.e. more than half of the public underground network asset consists of sewage systems. It is apparently extraordinarily costly to lay many kilometres of large pipes in considerable depths, mostly in the middle of the street. Annually, approximately 4 billion Euros are allotted to sewage investments so that utilization duration of up to 100 years is not rare.

The municipal underground, however, is not only the location for supply and disposal lines. Furthermore, other bearers of public and private matters use it. Architects erect their buildings on it, road contractors and traffic planners see it as an extensive support structure, open-space-planning offices design it as substrate for the municipal green and water associations and use it for rainwater farming. In the underground in cities, it is usually therefore congested and obscure. Besides technical innovations, comprehensive goals and strategies are called for at municipal level. This is the prerequisite for appropriately shaping the underground infrastructure in technical regard.

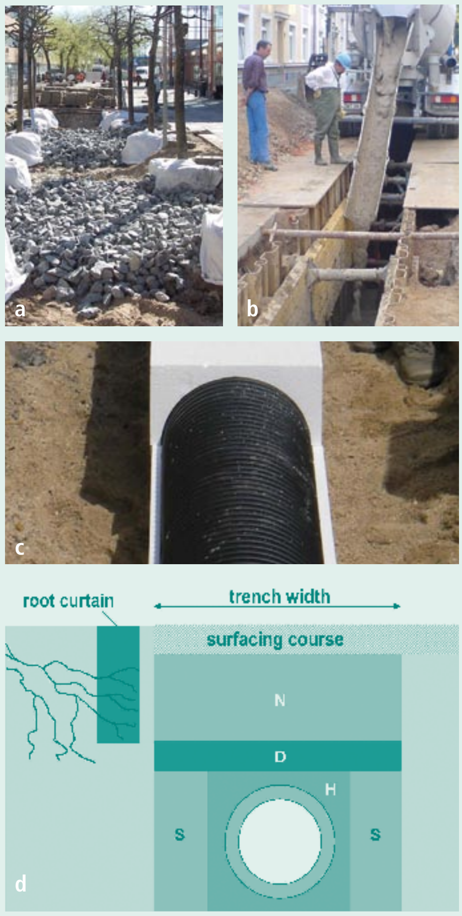
Technical developments thereby enhance the latitude for the objectives and choice of new concepts. In the following, current developments in sewer and pipeline construction are described, which are processed in manifold IKT projects with network operators and partners from trade and industry. The focal points are

- Soil and components
- Products, materials and procedures
- Consumer protection
- Risk analyses
- Construction of the sewer technology
- Innovations and markets

All these focal points are at disposal for the participation by interested partners.

Soil and components

Underground sewer and pipeline networks are more than just stringing together pipes and manholes. The engineering structural utility trench consists - similarly to building construction - of foundations, support rack, and slab. The development of novel bedding and filling materials starts here. Flow-capable self-compacting filling materials [1] and innovative bedding cushions, for example made of EPS [2], secure the laying quality and can assume many other functions, for example, as vegetation substrate, barrier layer, thermal insulation or drainage body (cf. [3], [4]).



a) Use of coarse-grained material in plant pits for rainwater farming, from [4]; b) Installation of flowable self-compacting filling materials in narrow trench width; c) EPS bedding cushions as cover zone; d) Utility trench with multifunction trench zones: N – Utilization, D – Cover layer, S – Side filling, H – Cover zone.

Products, materials and procedures

The technical development of new products, materials, and procedures demands also new concepts for quality assurance. Innovative measuring systems for pipe-jacking, permits, for example, already during the jacking, to record structural stresses of pressure transmission means and detect risks in advance [5]. The acceptance of in-situ-quality of curing products on the spot such as tube liners and textile cladding can be supported through non-destructive testing procedures [6]. The construction, and third party monitoring of the construction and rehabilitation firms is to be questioned as well, (cf. [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17]). IKT quality reports will further pursue quality development and activate improvements on the market [18]. For the special area of the estate draining, training and further training measures are offered [19].

Pipe-jacking: IKT online measurement of pipe offset;
above: Radio controlled capsule in on-site use;
below: Measuring system setup; from [5]

Consumer protection

Underline current legal changes (cf. [20]): „Integral water economy starts on the plot“. That applies to leaky sewage pipelines just as to the handling of incorrect connections, rainwater uncoupling as well as little drinking water usage. Measures in the private area demand that the community also takes measures for consumer protection, up to the consultation obligation. Members of the IKT-Association of Network Operators have established the municipal network for estate draining (KomNetGEW, see www.komnetgew.de). Concepts for handling estate draining, materials for civil information, monitoring for experts of water-tightness test as well as consultation and training in all technical aspects of estate draining are central network services.

IKT product tests as neutral and independent product and procedure comparisons offer further consumer protection. More than one hundred network operators were previously involved in these tests and contributed in financing them. Product tests for the restoration of estate draining are concluded (see page 45). Further tests on decentralised rainwater farming are in preparation.

Risk analyses

External boundary conditions for construction, operation, and rehabilitation of the networks are characterised among others through demographic and city structural developments as well as consequences of possible climate change. For network operators, the question is which risks and imponderability cases are expected and how are the operation, maintenance and investment strategies to be accounted for in future. Risk analyses should recognize need for action and propose meaningful immediate measures. Mostly, damage risks can already be excluded with simple means. Backwater risks are an example from strong rain events with obvious immediate measure of coordinated installation of backwater safety devices in private plants.

Long-term risks must also be included in the life cycle strategy. Which binding durations for technical solutions are reasonable? Which flexibility is called for? The IKT intends to develop adapted and well-balanced approaches to the evaluation of utilization period, durability magnitudes, and financing ties.

Construction of the sewer technology

With the conclusion of the first coverage of sewage systems, the special constructions such as sewer manholes shafts, precipitator, rain basin, and culvert move into the consideration field of view. That nationally acknowledged test body for flow measurements of the IKT supports selection, maintenance, and evaluation of measuring instruments and offers the operating personnel special expertise training on calibration of throttling devices. The effectiveness of cleaning and rinsing devices as well as sieves and rake on rain basins is investigated in experience exchange and joint projects of the network operator. Further operational questions involve explosion protection, reliability of climbing aids, the ease of handling of tools and the cleaning and structural assessment of pressurized lines.

Structurally, procedures and materials for concrete and masonry restoration are becoming more important in the sewage sector. This relates especially to seals, coating, and cladding procedures, which are investigated in detail in an in-house research and test.

Foam pigs in the IKT test:
above: PU/Foam scraper with location transmitter:
below: Removal of larger pushing and shoving quantities with foam pigs

Manhole rehabilitation:
above: Investigations in the IKT large scale test facility on 21 sewer manholes,
below: View into 6 meter deep test manhole

Innovations and markets

Ideas that are already transferred into new products, services or procedures and that also find actual successful use or that have even penetrated into the market can be designated as an innovation. Here, the IKT offers the connection between the IKT-Association of Network Operators and IKT-Association of Industry and Service.

In close contact to the IKT-Association of the network operators, bottlenecks of present technologies are recognized and are concretised as an innovation requirement. A current example is the reliability of water-tightness tests and monitoring of new bedding and filling materials.

Technology trends are set as a rule in highly innovative sectors such as medicine and telecommunication. These trends are to be evaluated for the underground sewer and pipeline construction. Examples are new camera systems for building monitoring and application areas of new materials.

The launch of innovative products and procedures is supported by technical proofs and standards. Continuing goal is the inclusion of innovative technologies into the requirements profiles of the network operator.

Outlook

The functionality of underground supply and disposal networks contributes substantially to the quality of life in our cities. Nevertheless, it remains further congested and obscure in the underground of the cities. In order to reduce an „aimless disorder" of different bearers of public concerns in the underground, the overall goals of urban development must first be determined at the municipal level. The technical developments in the sewer and pipeline construction thereby increase the freedom of action and identified focal points show much promising perspectives. The IKT – Institute for Underground Infrastructure pursues this further and appeals to network operators and industry, to always contribute new ideas, concepts and technical solutions for joint projects.

Author

Dr.-Ing. Bert Bosseler
Research Director

References

[1] Ausführungsrisiken beim Einsatz von Bettungs- und Verfüllmaterialien im Rohrleitungsbau. Endbericht zum Forschungsvorhaben, gefördert durch das MUNLV NRW, Ruhr-Universität Bochum, Lehrstuhl für Grundbau und Bodenmechanik und IKT - Institut für Unterirdische Infrastruktur, Bochum Gelsenkirchen, 2006.

[2] EPS-Bettungskissen in der offenen Bauweise. Endbericht zum Forschungsvorhaben, gefördert durch das MUNLV NRW, IKT - Institut für Unterirdische Infrastruktur, Gelsenkirchen, 08/2007.

[3] Bäume, unterirdische Leitungen und Kanäle, Arbeitsbericht der DWA-Arbeitsgruppe ES 3.6 „Baumstandorte, Kanäle und Leitungen". KA Korrespondenz Abwasser 56, S. 240-243, 03/2009.

[4] Embrén, B.; Bennerscheidt, C.; Stål, Ö.; Schröder, K.: Optimierung von Baumstandorten. wwt wasserwirtschaft wassertechnik, 07-08/2008.

[5] Liebscher, M.; Redmann, A.; Bersuck, F.: Neuartiges System zur Fugenvermessung beim Rohrvortrieb – Praxistest; 3R International, 01/2010.

[6] Diburg, B.; Kuchenbecker, R.; Weber, M.: Praxiseinsatz innovativer Inspektionstechniken und Prüfverfahren in einer linersanierten, begehbaren Prüfstrecke. 3R International 07/2009.

[7] Eignungsprüfung von Verfahren zur Sanierung von Schachtabdeckungen. Endbericht zum Forschungsvorhaben, im Auftrag des Stadtentwässerungsbetriebes Düsseldorf, gefördert durch das MUNLV NRW, IKT - Institut für Unterirdische Infrastruktur, Gelsenkirchen, 11/2002.

[8] Qualitätseinflüsse Schlauchliner - Stichproben-Untersuchung an sanierten Abwasserkanälen. Endbericht zum Forschungsvorhaben, gefördert durch das MUNLV NRW, IKT - Institut für Unterirdische Infrastruktur, Gelsenkirchen, 12/2003.

[9] Sanierung von Hausanschlussleitungen -Pilotprojekt Stadt Würselen-. Endbericht zum Forschungsvorhaben, im Auftrag der Stadt Würselen, gefördert durch das MUNLV NRW, IKT - Institut für Unterirdische Infrastruktur, Gelsenkirchen, 01/2004.

[10] Profilierte Großrohre aus Kunststoff – Praxiserfahrungen und Prüfkonzepte. Endbericht zum Forschungsvorhaben, gefördert durch das MUNLV NRW, IKT - Institut für Unterirdische Infrastruktur, Gelsenkirchen, 12/2005.

[11] Beschichtungsverfahren zur Sanierung von Abwasserschächten – Studie zu Qualitätseinflüssen und Einsatzgrenzen anhand von Praxis- und Laboruntersuchungen -. Endbericht zum Forschungsvorhaben, gefördert durch das MUNLV NRW, IKT - Institut für Unterirdische Infrastruktur, Gelsenkirchen, 02/2005.

[12] Anschlusskanäle und Grundleitungen - Schäden, Inspektion, Sanierung -. Endbericht zum Forschungsvorhaben, gefördert durch das MUNLV NRW, IKT - Institut für Unterirdische Infrastruktur, Gelsenkirchen, 12/2005.

[13] Entwicklung eines Prüfverfahrens für Schachtkopfmörtel. Endbericht zum Forschungsvorhaben, gefördert durch das MUNLV NRW, IKT - Institut für Unterirdische Infrastruktur, Gelsenkirchen, 09/2007.

[14] Gewährleistungsabnahme Schlauchlining. IKT - eNewsletter September 2008, IKT - Institut für Unterirdische Infrastruktur, Gelsenkirchen, http://www.ikt.de/index.php?doc=905, eingesehen am 14.01.2009.

[15] Abnahme von Linermaßnahmen, - Materialnachweise und Bewertung der Linerqualität -. Endbericht zum Forschungsvorhaben, gefördert durch das MUNLV NRW, IKT - Institut für Unterirdische Infrastruktur, Gelsenkirchen, 03/2009.

[16] IKT-Warentest „Hausanschluss-Liner". Endbericht, IKT - Institut für Unterirdische Infrastruktur, Gelsenkirchen, 11/2005.

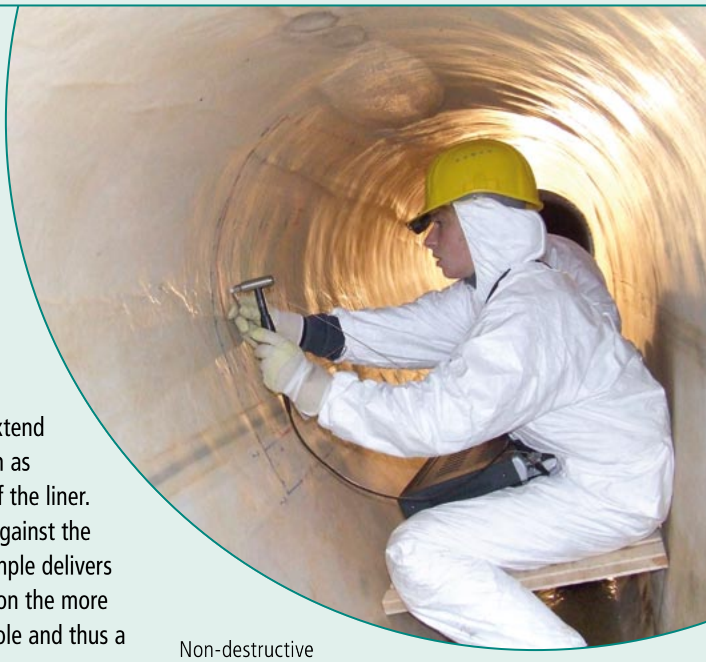
[17] IKT-Warentest „Reparaturverfahren für Hauptkanäle". Endbericht, IKT - Institut für Unterirdische Infrastruktur, Gelsenkirchen, 07/2009.

[18] Waniek, R.W.; Homann, D: IKT-LinerReport 2008, Schlauchlinerqualität: Tendenz uneinheitlich; bi UmweltBau, 01/2009.

[19] IKT-Lehrgang „Zertifizierter Berater Grundstücksentwässerung". IKT - eNewsletter Mai/Juni 2009, IKT - Institut für Unterirdische Infrastruktur, Gelsenkirchen, http://www.ikt.de/index.php?doc=1032, eingesehen am 21.03.2010.

[20] Wassergesetz für das Land Nordrhein-Westfalen - Landeswassergesetz - LWG vom 25. Juni 1995, zuletzt geändert am 06.12.2007. GV. NRW. S.926 / SGV. NRW. 77.GV. NRW. S. 708, hier §61a Private Abwasseranlagen.

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

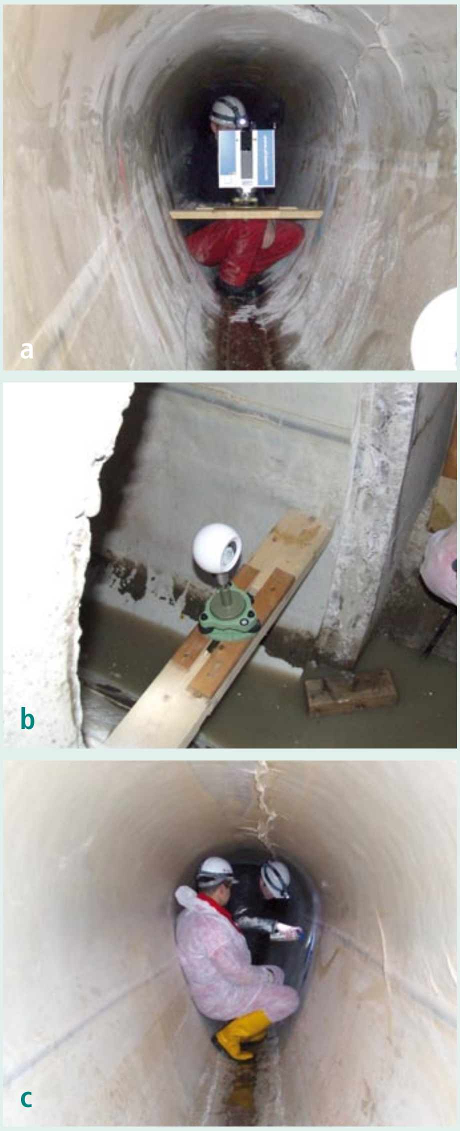
The start manhole was created anew in cast-in-situ concrete in advance of the rehabilitation project. To facilitate execution of the rehabilitation project, the concrete slab of the manhole was first left out and thus the accessibility of the rehabilitation stretch guaranteed for the liner.

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

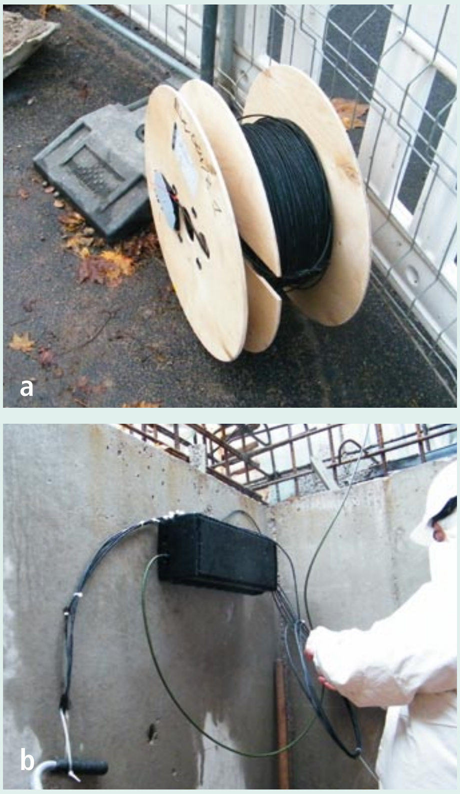
Appropriate tools are available for the analysis and representation of measured results, which enable visualization via an Internet browser. Based on retroactive preparation possibilities, for example storage of views, inserting of dimensions, tapping of coordinates, lengths and heights or insertion 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

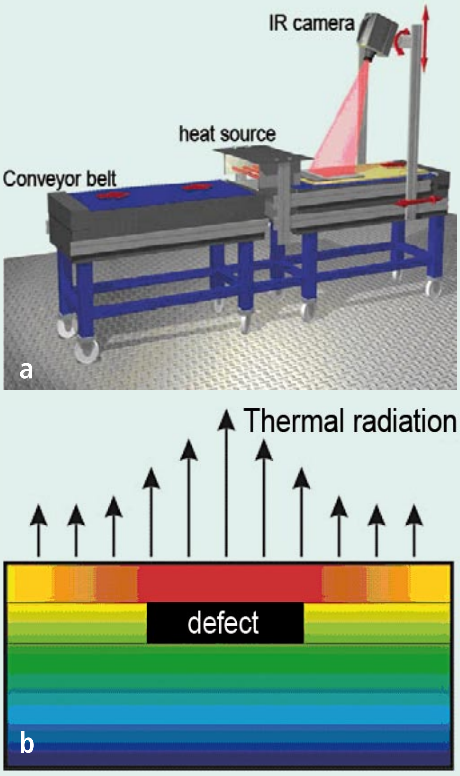
In the building project, fibre optical Raman temperature measurement (DTS = distributed temperature sensing) found application. The measuring system consists of an optoelectronic device (radar) and a fibre-optic cable (LWL cable) consisting of quartz optical fibre as a linear temperature sensor. The 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.

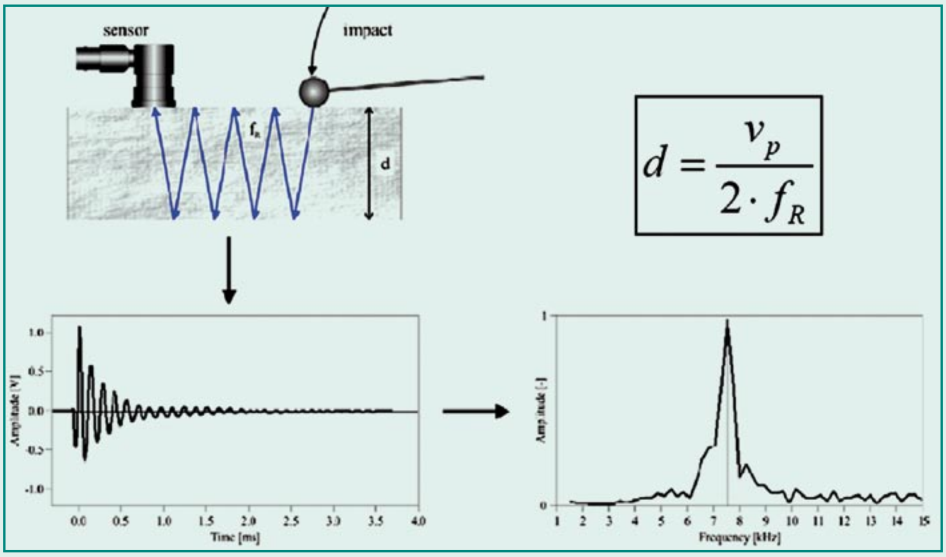
Impact echo procedure

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

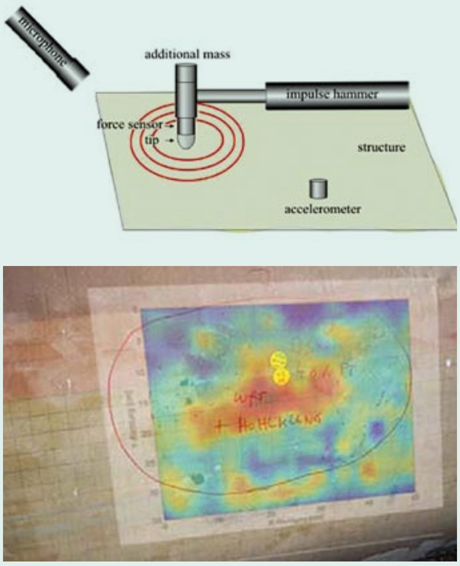
The local resonance spectroscopy orients itself (cf. [8]) towards manual knock tests that are used among others in the aviation and space flight or in the test of rotor blades of wind power plants. The component is knocked by the inspector with a suitable object and the sound thus stimulated is evaluated.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

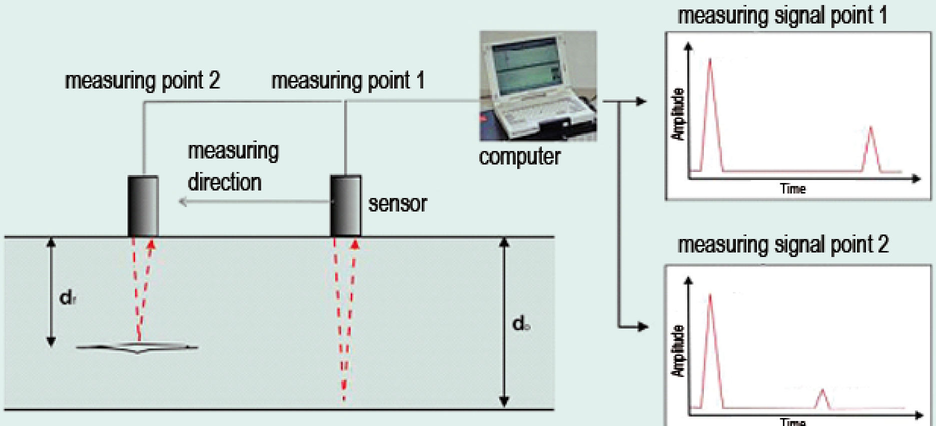


Local resonance spectroscopy [8]
a) Measuring principle
b) Analysis of the stimulation signals: Delamination in the GFK laminate

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.

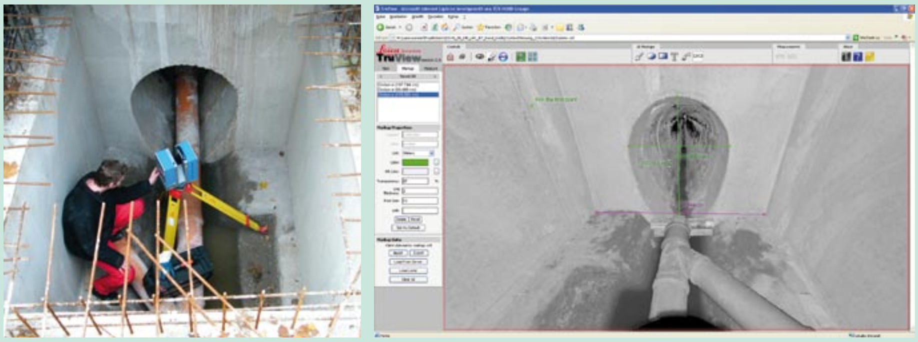
In contrast to the impact echo procedure and the local resonance spectroscopy, the ultrasonic echo procedure is a running time procedure, that is, the signals recorded here are observed in the



Measuring principle of ultrasonic echo procedure [9]

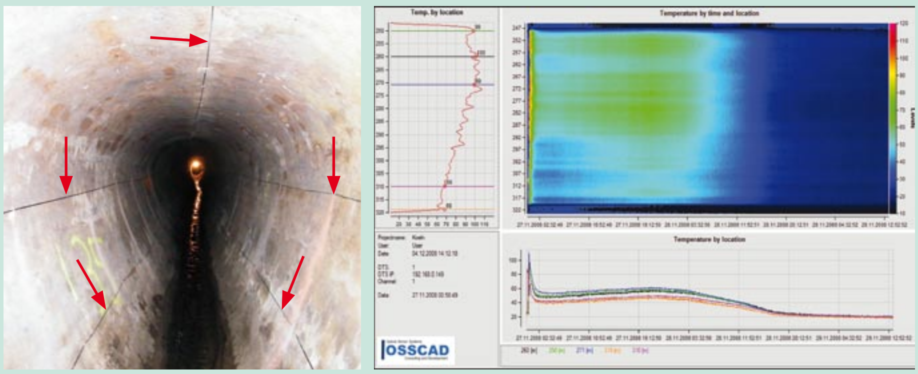
Photo examples for practical applications and measuring results

3D laser scanning (DMT, Essen)



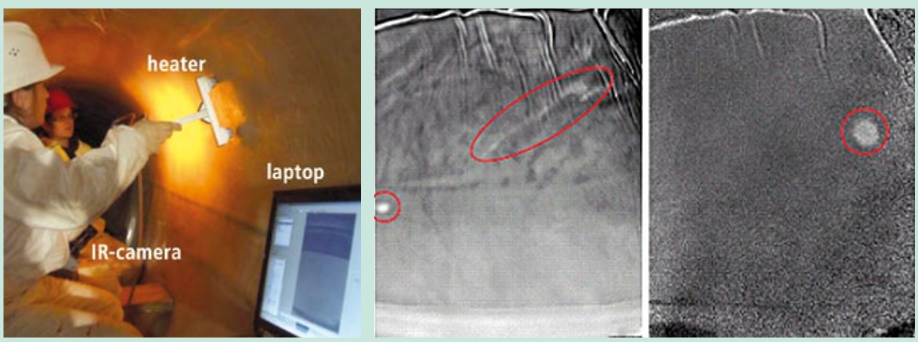
a) Surveying of the start manhole
b) Visualization of the readings

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 $d = v \times t/2$.

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

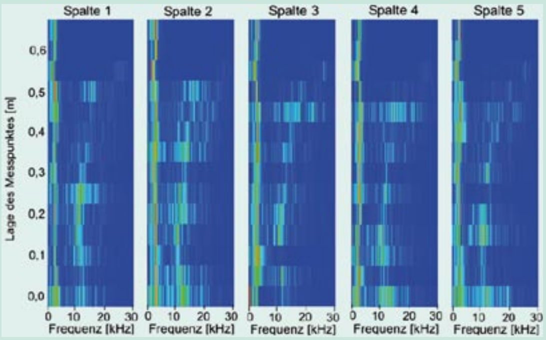
The tested non-destructive testing procedures were evaluated based on the construction site experiences with respect to their theoretical significance, practical usefulness, expense and costs as well as available improvement potential and compared against the classic standard sampling. In the table, 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)

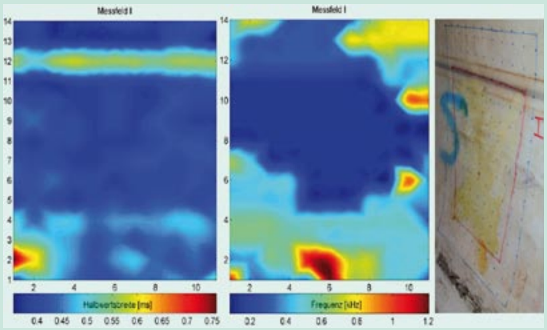
a) Measurement in the sewer



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

Local resonance spectroscopy (MPA Stuttgart)

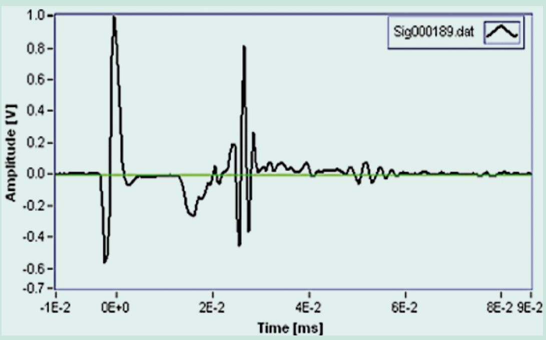
a) Measurement in the sewer



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

References

[1] Bosseler, B.; Sokoll, O.; Diburg, B.; Beck, S.: Abnahme von Liningmaßnahmen – Materialnachweise und Bewertung der Linerqualität -. Endbericht zum Forschungsvorhaben, im Auftrag des Ministeriums für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz des Landes NRW; IKT – Institut für Unterirdische Infrastruktur; Gelsenkirchen, März 2009.

[2] DMT GmbH und Co. KG GB Exploration & Geosurvey – Ingenieurvermessung und Geomonitoring: Messbericht „Dreidimensionale Erfassung eines Kanals in Köln (Ankerstraße; Haltung: 67440041 – 67440042) vor und nach Durchführung einer Sanierungsmaßnahme, mit dem Ziel einer Deformationsanalyse". Essen, Dezember 2007; unveröffentlicht.

[3] DMT GmbH und Co. KG GB Exploration & Geosurvey – Ingenieurvermessung und Geomonitoring: Interner Bericht. 2008; unveröffentlicht.

[4] Weber, M.: Untersuchung der Software JRC Reconstructor zur Registrierung von Punktwolken. Diplomarbeit FH Bochum; 2007; unveröffentlicht.

[5] Brocke, H.; Aderhold, J.: Wärmefluss-Thermographie zur Qualitätskontrolle in der Produktion. Fraunhofer Wilhelm-Klauditz-Institut für Holzforschung (WKI); Braunschweig.

[6] Fraunhofer Wilhelm-Klauditz-Institut für Holzforschung (WKI): Untersuchungsbericht „Thermographische Untersuchungen zur „Abnahme von Lining-Maßnahmen" – Vor-Ort-Einsatz in Köln". Braunschweig, Januar 2009; unveröffentlicht.

[7] Grosse, C.; Wiggenhauser, H.; Algernon, D.; Schubert, F.; Beutel, R.: Impakt-Echo. Kapitel 3 in: Betonkalender 2007 (Hrsg. Bergmeister + Wörner), Ernst & Sohn 2007, ISBN: 978-3-433-01833-0, S. 496-505.

[8] Materialprüfungsanstalt Universität Stuttgart: Verfahrensbeschreibungen zur lokalen Resonanzspektroskopie, zum Ultraschall-Echo- und Impakt-Echo-Verfahren. Stuttgart, August 2008, unveröffentlicht.

[9] Jüngert, A.; Grosse, C.; Aderhold, J.; Meinlschmidt, P.; Schlüter, F.; Förster, T.; Felsch, T.; Elkmann, N.; Krüger, M.; Lutz, O.: Zerstörungsfreie robotergestützte Untersuchung der Rotorblätter von Windenergieanlagen mit Ultraschall und Thermographie. Deutsche Gesellschaft für Zerstörungsfreie Prüfung (DGZfP), ZfP-Zeitung 115, Juni 2009, S. 43-49.

Sources: 3R international Ausgaben 7/2009, 12/2009 und 1/2010, gekürzt

Authors

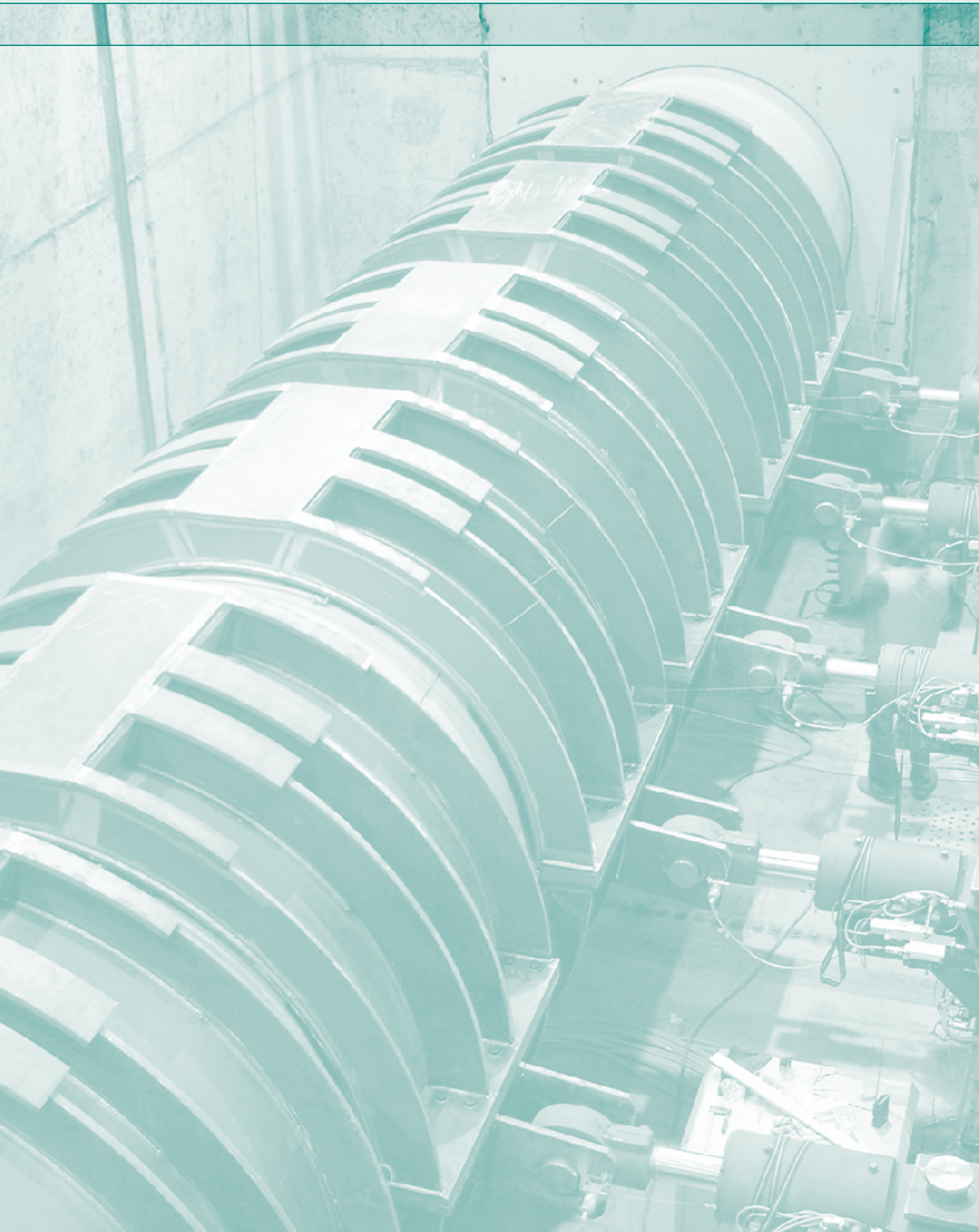
Dipl.-Ing. Bianca Diburg
IKT – Institut für Unterirdische Infrastruktur
c/o IKT-Süd, Neubiberg bei München

Dipl.-Ing. Rainer Kuchenbecker
Dipl.-Ing. Martin Weber
DMT GmbH & Co. KG, Essen

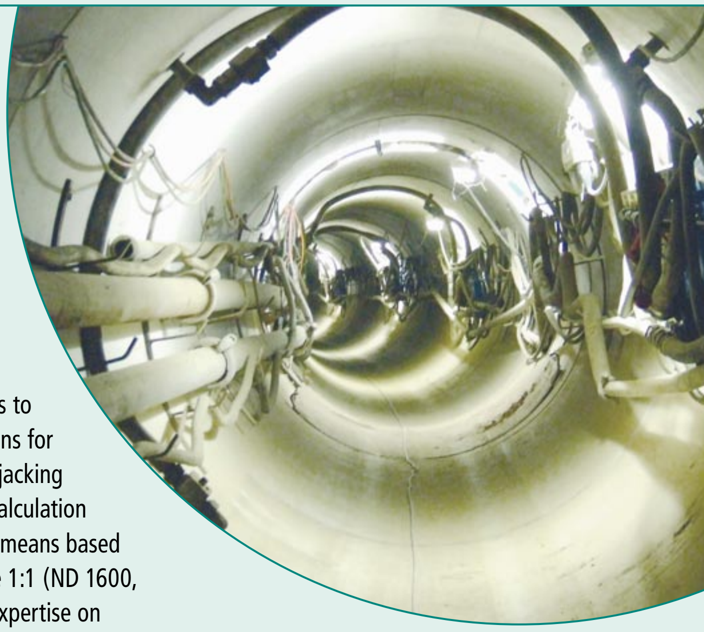
Dipl.-Geophys. Anne Jüngert
Prof. Dr.-Ing. habil. Dipl.-Geophys. Christian Große
Materialprüfungsanstalt Universität Stuttgart

Dr.-Ing. Jochen Aderhold
Dipl.-Phys. Friedrich Schlüter
Fraunhofer-Institut für Holzforschung
Wilhelm-Klauditz-Institut WKI, Braunschweig

Prof. Dr.-Ing. Ulrich Glombitza
Rheinische Fachhochschule Köln, Köln
c/o Rheinisch-Bergisches Technologie Zentrum, Bergisch Gladbach



Quality assurance in pipe-jacking



During pipe-jacking, the external loads from bedding and curvature of the pipeline remains concealed so far. Goal of the IKT research focus „pipe-jacking" was to make these loads visible for the first time and thus minimise risks for future jackings.

Test equipment

In the IKT – Institute for Underground Infrastructure, test equipment was developed within the framework of the research project „pipe-jacking" [1], with which jacking loads can be simulated in the scale 1:1 on pipes and pipe connections including the resulting bedding stresses. From the test results and in-situ-investigations, recommendations on optimization of pipe connections can be derived, for the planning and control of pipe jacking as well as for the measuring technology construction-site accompaniment and quality assurance. The project was promoted by the ministry for environment of the German State of North Rhine-Westphalia as well as the Emschergenossenschaft.

Target of the research project was to develop practical recommendations for the planning and control of pipe jacking as well as for the selection and calculation of suitable pipes and connection means based on jacking simulation in the scale 1:1 (ND 1600, Figure 1). In this case, previous expertise on the behaviour of pipes under jacking loads was to be investigated, where appropriate, corresponding load models were to be developed and relevant influence factors to be identified. It appeared that pipeline kinematics and bedding reactions of currently recognised calculations and dimensioning assumptions (cf. [2]) can deviate. Within the framework of planning and construction-site accompaniment, the calibrated, mathematical model can also be used for quality assuring jacking simulation.

In the following passage, quality-relevant aspects are worked out both in decisive components and materials as well as in planning, execution, and acceptance of pipe-jacking.

Figure 1 jacking simulator ND 1600 with side hydraulic cylinders

Focus of action

Within the framework of quality assurance in pipe-jacking, the focus of action lies in the following phases of a jacking project:

Planning

In the planning of pipe-jacking, many parameters are already determined, which have great influence on the quality of the design, for example, pipeline routing, pipe material and the pressure transmission device or the arrangement and formation of main stations and intermediate jacking stations. All these factors also affect the measures to be selected for quality assurance.

Components and materials

If components and materials were selected within the framework of the planning, then the possibility exists to subject these different tests and monitoring in order to guarantee especially constant quality during production and transportation.

Construction

Within the construction framework, it all depends on properly installing already tested components and materials. Here it especially concerns load application to the main station and intermediate jacking station, the positional accuracy in horizontal and vertical direction and compliance with other basic data, like for example the support and/or lubricant.

◉ Building and guarantee acceptance

During acceptance of a pipe-jacking project, it involves subjecting the finished and ready building to a concluding inspection. In this case, for the service lives of up to 100 years desired in some cases, suitable procedures and tests are to be selected for a comprehensive assessment.

Planning

For the planning of pipe-jacking, numerous conclusions can be derived from the IKT research focus. Thus the line routing should be selected, for example, such that the planned curve radii and therefore the offset angle in the pipe connections lie clearly under the value allowable for pipe and connection according to DWA-A 125 [3], because by unplanned control movements and grouping effects considerable offsets can come in to play.

In addition, „winding" stretches can lead to an increase of the required jacking force based on increased jacket friction. This is also to be considered in the dimensioning of the jacking stations.

Based on considerable influence on line routing choice and jacking force, the pressure transmission device should be tested regarding material characteristics already during the planning phase. This should serve as a base for dimensioning the pipes and connections.

In special cases, the computer simulation can also be meaningfully under variation of significant parameter for verification of feasibility of a jacking project.

Component and materials

◉ jacking pipes

Requirements are made on jacking pipes made of reinforced concrete, for example, with respect to the finish, dimensional accuracy, strength, water tightness, and resistance to chemical attacks. Besides the quality of used aggregates, the forming and compaction process is decisive for the quality of the pipes. The manufacturing procedure and degree of mechanization of the manufacturing process can differ from one pipe manufacturer to the other. In the manufacture of concrete and reinforced concrete pipes, one distinguishes between procedures with immediate form stripping and procedures with hardening in formwork, which are used nearly exclusively for jacking pipes of larger nominal widths.

With this background, it appears meaningful to inspect the works coming in question for pipe production prior to contract award. In this case, the entire production process should be reviewed, starting with the delivery of original materials via the production of pipes up to the follow-up treatment. In the result, the production process can assessed and essential requirements if necessary taken over in the tender.

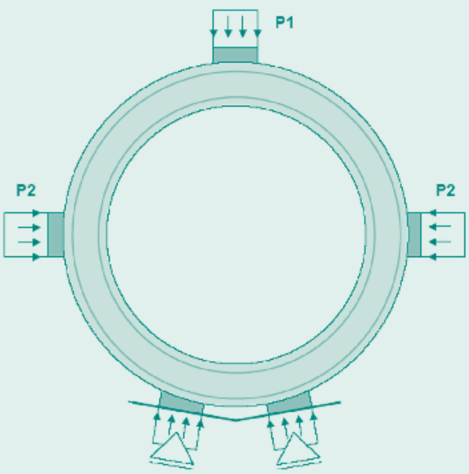
Within the project framework, the IKT researchers dealt with dimensions and dimensional tolerances for jacking pipes. Here it appeared already before production start that measurement of the pipe form could be meaningful in order for example to cover system-related geometry deviations. Furthermore, pipes produced in the factory or on the construction site can be appraised optically and measurement with respect to jacking specific parameters in order to rule out jacking problems related with dimensional tolerance.

In the manufacture of jacking pipes, as a rule, high-quality concretes can be used. Through hardening of pipes under defined temperature and moisture conditions, the load-bearing behaviour can be improved additionally. The effect of contingent cracks on the load-bearing behaviour can only be judged certainly if besides visible crack width also the fabrication quality and reinforcement content of the pipe are considered. Reinforced concrete pipes are distinguished compared to pipes made of other materials in that they always especially dimensioned, reinforced, and made for the respective application case. Correspondingly, also the test conditions must be adapted to the jacking loads, as this was already implemented in the jacking simulator.

For loads in the operating condition, which is after conclusion of the jacking load, a near-reality test of pipes made of reinforced concrete is described in [4]. The load of underground sewers in operation is substantially characterised by vertical and horizontal pressure stresses from soil and traffic loads. Crown pressure tests on reinforced concrete pipes were restricted nonetheless to the single-axial (vertical) load of the components. The multi-axial pressure portal represented in Figure 2 allows simultaneous vertical and horizontal introduction of external loads under defined loading conditions, as „modified crown pressure test". The component cross-section to be tested in the pipe crown is excluded from the calculation stresses from normal forces and bending moments, so that the crack characteristic and especially the crack widths in the test correspond to the actual behaviour under dimensioning loads.

The targeted use of this novel test technology permits risks for the stability and tightness of the pipe dimensioned for the individual case already directly after fabrication and/or special

Figure 2 „Modified crown pressure test" in the multi-axial pressure portal of the IKT [4]



constructions to be ascertained by means of appropriate test proofs. The following cases can be distinguished:

- The reinforced concrete pipes are tested random sample-like within the framework of the internal works quality assurance for the calculation case. This is especially recommended if, for costs or quality reasons, deviation should be made from the standard specification, for example when choosing smaller wall thicknesses with increased reinforcement levels. In the open method of construction, this is meaningful, for example, in the calculation of line support. Because it concerns a non-destructive test (first cracks under calculation loads), tested pipes can be used further, subsequently.

- The client demands a random sample-like proof of the crack pattern before installation, in order to exclude later cases of damage based on insufficient pipe quality. This is recommended especially if the calculation loads appear first at the end of the guarantee period, for example, in traffic loads increased in the future or further coverings.

- Pressure transmission device

The pressure transmission device has great influence on the success of pipe-jacking. The force transmission in transverse and longitudinal direction is influenced substantially through the characteristics of the pressure transmission device as well as the formation and dimensional accuracy of the pipe connection construction. Therefore, according to the suitability test to be carried out in the planning phase, the constant quality should be verified by random samples with the jacking-accompanying test procedure developed by the IKT. Moreover, reset samples should be taken from the pressure transmission device, which can be subjected to tests further in unpredictable events within the scope of the jacking.

Construction

In contrast to new construction in open method of building, the possibilities of client's influence on the quality of the building already seem exhausted at the start of design. From the results of optical inspections, measurement of the pipeline as well as analysis of the pre-jacking forces, conclusions on the condition of the building can always be drawn. Thus, continuous recording of forces on the main and intermediate stations is indispensable. Also at least when lubricant is used the injected quantity and pressure should be recorded time-dependently. In addition, the possibility exists to use more complex, partially automated systems, which can precisely allocate quantity, pressure, and location for jacking.

a) Improper support of the pressure transmission devices

b) Dirt of a gaping joint in the sole area

Figure 3 Striking features during visual inspection

The location accuracy of the pipeline is determined continuously in horizontal and vertical direction and is reviewed at particular points mostly by independent surveying office. Target of measurement is the inspection of the pipeline routing with regard to the default nominal routing. Pipeline routing thus determined do not allow conclusions to be drawn about offsets in individual pipe connections, which decisive influence on the pipe load.

In order to gain further information on the jacking, the following procedures are available.

Visual inspection

The already completed section of jacking is appraised at regular intervals. Hereby, attention is not only paid to ensure that pipes are not damaged, but also to constructional engineering influence. Thereby, for instance, support of pipes and pressure transmission rings or reception of noticeably large or small joint gap dimensions are of importance. In addition, problems in construction sequence can be recognized and if necessary countermeasures taken (Figure 3).

Local measurement

The decisive calculation-relevant stress on pipes already occurs during pipe-jacking in the construction phase. The pre-jacking force initiated in the start construction pit is forwarded by the pressure transmission device in the pipe connections by the pipeline up to the jacking machine. The measurement of deformation of pressure transmission device on the one hand permits approximate inspection of positional accuracy of the pipeline, on the other hand it shows the stress distribution and hence the stress in pipe connections.

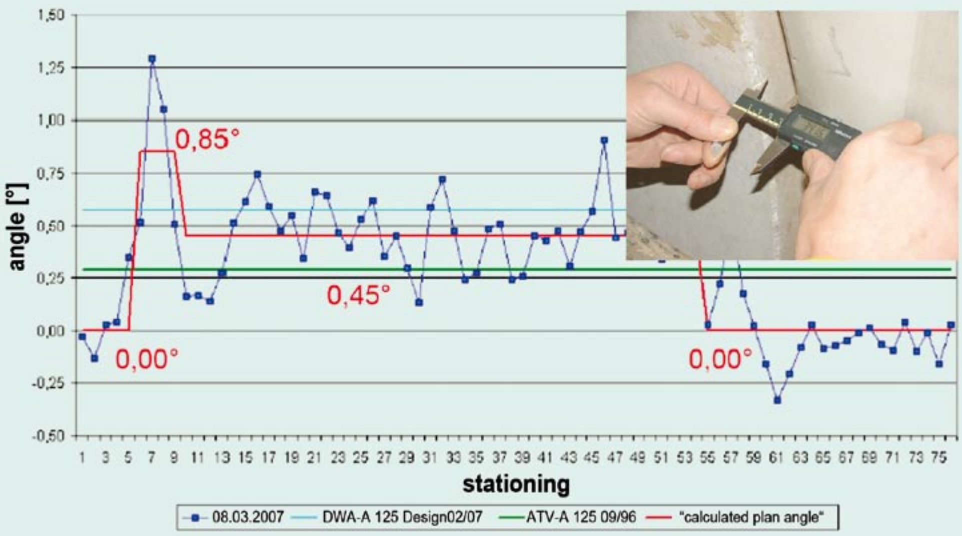


Figure 4 Measurement and corresponding analysis of the joint gap width with a slide rule

Within the framework of jacking, individual pipe connections or also the entire pipeline can be measured manually by random samples. For a measurement, a standard slide rule can be used for example (Figure 4). Experience shows that within the jacking recesses an entire pipeline can be surveyed. By comparison, of several measurements carried out, „problem points" with large offsets joint gaps can be determined. In addition, the driven routing line can be determined by approximation.

Continuous measurement

In winding jacking sections, especially with oppositely oriented curves, the pipe connection area and the pressure transmission device are subjected to high stress. If the elastic deformation share of the pressure transmission device is too low, gaping joints appear and force transmission occurs solely in partial sections of the pipe. Overloading stress up to spalling can be the consequence.

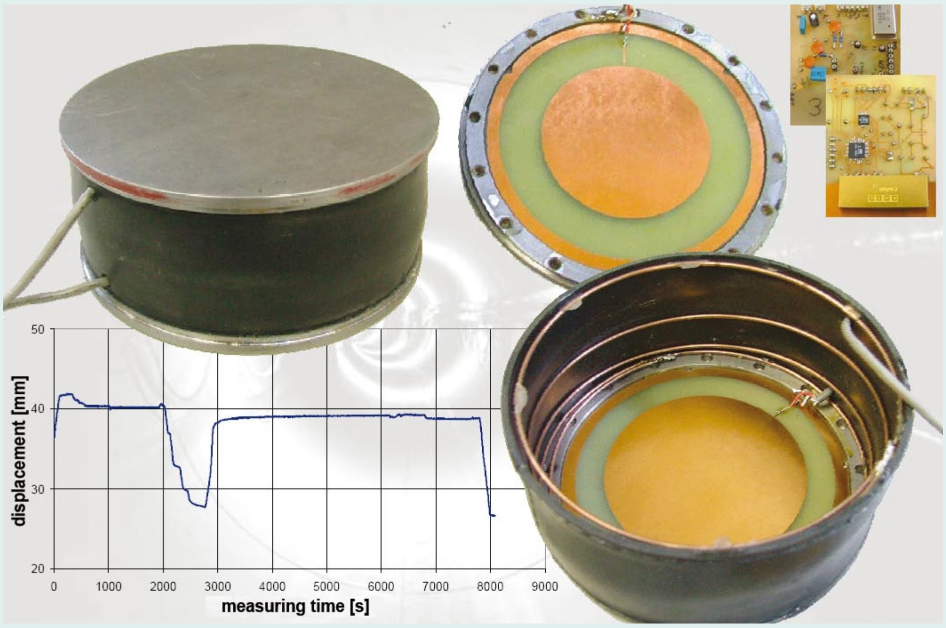


Figure 5 Design of the deformation load cell

The continuous measurement of the joint gap facilitates monitoring of the deformation of the pressure transmission device over the entire stress time. Threatening overloads of jacking pipes can be recognized early and countermeasures, for example, increase of bentonite lubrication initiated to reduce the jacket friction and reduction of the pre-jacking forces.

Current practice in quality assurance monitoring of pipe-jacking is the measurement of the joint gap width with displacement transducers in the pipe connections. At the same time, displacement transducers are installed inside the pipe. Additionally, safety against pipes rolling away is required here. Open installation inside the pipe conceals the danger of damage. The readings are transmitted via cable from the starting pit so that in every pipe change also the measuring cables must be disconnected and reconnected again.

Starting points are being developed by the IKT at present to improve this situation. On the one hand, the measuring point is transferred into the area of the pipe end and on the other hand the measuring data is carried transmitted by wireless means. The pressure transmission device is left out in order to insert a special deformation load cell (Figures 5 and 6) with radio transmission. Disturbing installations in the pipeline are omitted. A mechanical lock against rolling away is not required.

The deformation load cell is constructed fundamentally like a two-plate capacitor. It consists of two differently charged plates opposite one another. A physical quantity designated as capacitance is measured. This capacitance of the two plate capacitors, i.e. the capacity to store an electric charge depends on the size of the plates, its soaking, and the material between the plates (dielectric). The quantity of electric charge fed in is understood at the same time as an electric capacitance. In a defined plate size and a constant dielectric, the capacitance is proportional to the distance between the plates.

If the distance between the plates decreases, the capacitance increases. The deformation measurement that is the measurement of capacitance, first become practicable by using one special analogue-digital-converter and in a resolution of 24 bits sufficiently exact. The measuring accuracy of the deformation derived from the measured capacitance change is about ±0.1 mm.

The readings are transmitted wireless to the starting pit and from there further. The possibility of an online query via Internet is planned for the future.

At present, the first prototypes of the cells and the radio transmission system are being tested in practice. In case of critical deformation of pressure transmission device, the check samples taken can be exposed to an identical loading scenario in a laboratory press based on the readings of the measuring cells in order to determine the remaining reserves. Based on this information, specifications can be made for continuation of the jacking.

Which of the procedures described here for the supplementary quality assurance finds application to in the end depends essentially on the complexity of jacking? For short straight jacking in controllable soil, a regular visibility test can already be sufficient. In difficult routing lines with opposite curves and critical passages under the building, the continuous monitoring is more convenient.

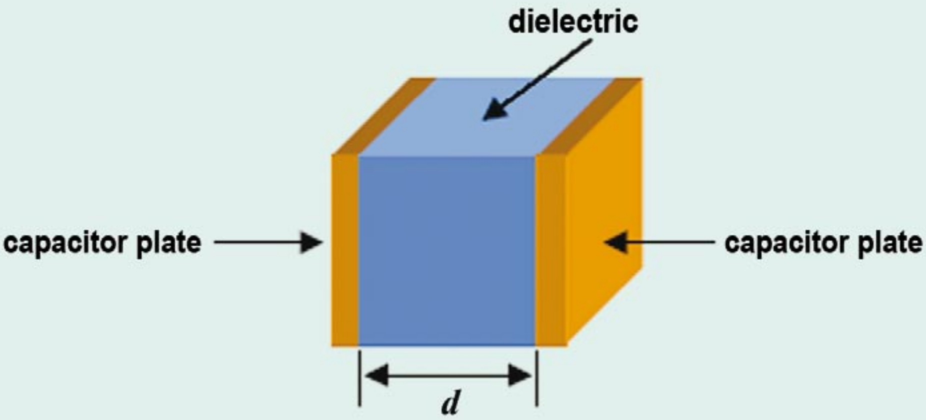


Figure 6 Functioning principle of the deformation load cell

Construction acceptance

Within the scope of construction acceptance, the protocols of the main and intermediate jacking stations as well as the protocols regarding the lubricant should first be examined for striking features. Here attention must be paid especially to high jacking forces or large lubricant quantities. Obligatorily a leakage-tightness test should be carried out at least on the pipe connections.

Supplementarily a joint end measurement can be carried out by hand after conclusion of the jacking. In connection with the jacking protocols, this can give hints to contingent problem points, for example in the form of large offsets or noticeable joint gap widths. If necessary, the boundary conditions for the tightness test must be adapted.

Within the scope of acceptance, a pipeline walk-through should be carried out. Here attention must be paid especially to cracks, leaks or other striking features.

Conclusions

With the background of experiences from the research focus, the following measures are proposed:

- The material characteristic values decisive for jacking of the pressure transmission device should be determined already in the planning phase. Tests to guarantee constant quality should be carried out in accompaniment to jacking. Check samples should be held in supply for special tests in critical jacking situations.
- The quality assurance of the jacking pipes can already start before production starts. In this way, the production conditions in the works can be reviewed and forms, finished products in the works and on the construction site can be measured.
- Reinforced concrete pipes are measured always for the individual case. Quality test under near-reality loads as random samples are suitable particularly in special constructions and expected load increases.
- At suitable intervals, the pipeline should be appraised optically in order to recognize striking features and to be able to take correction measures.
- The construction accompanying measurement of all pipe joints, for example with a slide rule can deliver important hints to pipe stress, and can localise critical areas with view of construction acceptance.
- A measuring system integrated directly in the pressure transmission device for joint gap width measurement with wireless transmission of the readings is presently being tested in practice by the IKT. Hereby, especially the obstruction of construction process should be minimised by means of measuring instruments and the number of measuring joints be increased.
- With the help of continuous joint measurement, the entire deformation and thus the loading history can be understood. It is possible to react immediately to critical situations. In cases of doubt, the current actual condition and available reserves can be determined with the help of reference sample of the pressure transmission device. Mathematically, this is possible only to some extent owing to complex material characteristics.

Type and scope of the quality assurance measures must be determined for the individual case.

Authors:
Dipl.-Ing. Martin Liebscher,
Dipl.-Ing. Frank Bersuck,
IKT - Institute for Underground Infrastructure

References

[1] Bosseler B., Liebscher M., Redmann A.: Der IKT-Vortriebssimulator – Entwicklung, Bau, Versuche und Ergebnisse, Endbericht des IKT – Institut für Unterirdische Infrastruktur im Auftrag des Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz des Landes NRW; Gelsenkirchen, Juli 2007.
[2] Arbeitsblatt A 161: Statische Berechnung von Vortriebsrohren, Regelwerk der Deutschen Vereinigung für Wasserwirtschaft, Abwasser und Abfall (DWA), St. Augustin, Januar 1990.
[3] Arbeitsblatt A 125: Rohrvortrieb und verwandte Verfahren, Regelwerk der Deutschen Vereinigung für Wasserwirtschaft, Abwasser und Abfall (DWA), Entwurf, Februar 2007.
[4] Bosseler, B.; Redmann, A.: Stahlbetonrohre in offener Bauweise – Rohrprüfungen unter realitätsnahen Beanspruchungen; Endbericht zum Forschungsvorhaben „Qualitäts- und Kostensicherung beim Bau begehbarer Abwasserkanäle aus Stahlbetonrohren" im Auftrag des MUNLV NRW; IKT- Institut für Unterirdische Infrastruktur, Gelsenkirchen. 09/2003, download www.ikt.de.

Source: bi UmweltBau 4/2008


neutral
unabhängig
gemeinnützig
IKT
IKT – Institut für Unterirdische Infrastruktur

Shallow covered waste-water conduits

Test apparatus for minimum soil cover of conduits

Shallow conduit coverings are of particular interest since, on the one hand, such applications are increasing and, on the other hand, the pipes are exposed to high soil stresses resulting from live traffic loads. In a recently completed research project [1], 1:1 scale tests and FEM simulations were used to determine the load situations for the pipe under various depths of cover.

Transverse earth pressure from live traffic loads

Since 1984, static calculation of soil-buried waste-water lines and conduits has been performed in accordance with ATV-DVWK code A 127 [2]. Two options for „European pipe statics" were, it is true, drafted within the framework of CEN/TC165/WG12, but no agreement on a finalized procedure was reached. The DWA ES 5.5 workgroup is therefore preparing a 4th edition of the A 127 code, in order to take into account further developments in pipe production and installation, and the necessity of conforming to customary European provisions concerning stability. It will also be possible in this context to incorporate more recent know ledge concerning the load-bearing mechanism of the pipe/soil system.

These investigations are also intended to supply information on the residual stability of damaged pipes and on calculation of repair systems for existing pipes no longer capable of bearing the relevant loads alone. Typical loads acting on shallow covered conduits take the form of vertical loads exerted on the pipe crown with only slight transverse reinforcement from earth pressure, longitudinal load-bearing by the pipes from concentrated surface loads, and load concentrations at the pipe crown (load bridge), see [3].

The horizontal support force resulting from wheel loads on the surface are firstly to be examined in more detail; when Cover h is kept constant in accordance with Figure 1 and external pipe diameter is enlarged, the vertical stresses adjacent to the side zones of the pipe decrease. A geometrical criterion including the values h, da and a therefore applies for the reinforcing transverse pressure. The tests performed provide measured data sufficient for verification of the equations. In the case of flexible pipes, the lateral reaction pressure and bedding reaction pressure are measured together, and these tests are therefore performed on a rigid pipe material.

Live traffic loads in accordance with DIN Technical Report 101

The magnitude and distribution of the loads resulting from the twin axles of the two heavy-goods vehicles can be seen in Figure 2. Unlike the previous provision, tire contact areas of 40 x 40 cm², inter alia, are included, the wheelbase has been reduced, the total load of the vehicles is now 4 x F_1 = 480 and 320 kN (previously 6 x F_1 = 600 and 300 kN) and the impact factor is now included (previously: 1.2 for HGV 60 and 1.5 for Truck 12).

In view of the increase in heavy-goods traffic (see the traffic forecasts published by the Federal Ministry of Transport, Building and Urban Affairs [BMVBS] for 2015 [4]) – intense two-way traffic must also be anticipated within built-up areas. The effects of overtaking vehicles on pipes were investigated by Hornung for the previous DIN 1072 standard, see [5].

Tests were performed both with a 60 cm clearance for 3 m wide traffic lanes (NL = „normal load position") and for narrow wheel positions (EL). According to DIN Technical Report 101 [6], traffic lanes widths of 2.7 m are possible with unobstructed wheel spacings of 10 cm, see Figure 2, but it was possible, for technical reasons, to reduce the spacing only to 25 cm. An approx. 1.4-fold increase in load compared to NL was measured in this context.

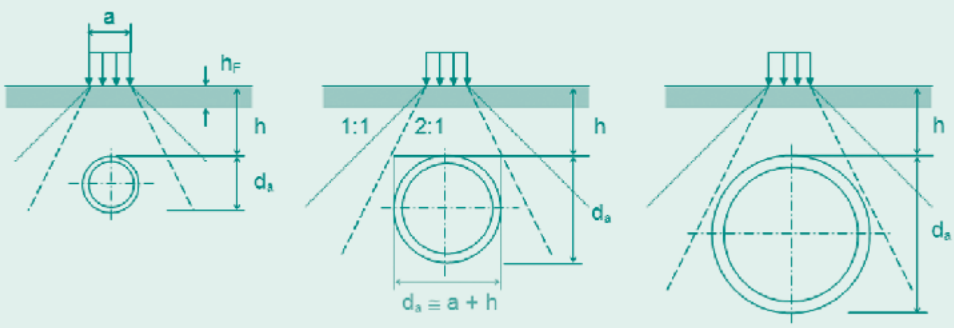


Figure 1: Stress distribution of partial surface load in the soil for constant cover depth and various nominal diameters (diagram in principle)

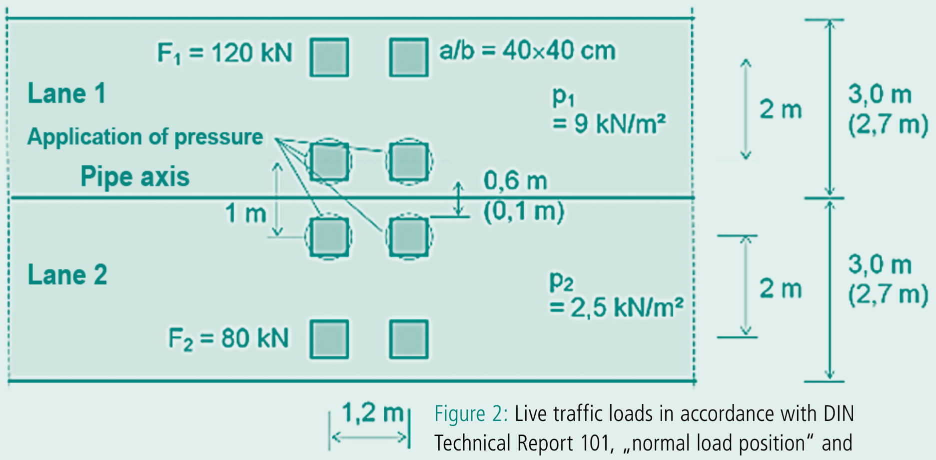


Figure 2: Live traffic loads in accordance with DIN Technical Report 101, „normal load position" and arrangement of presses for the load tests

Figure 3: Installation of profiled polyethylene pipes, structure of pipe wall

Further investigation targets

The tests on shallowly covered pipes consisting of concrete, ductile cast iron and polyethylene were intended to examine not only the magnitude of the transverse earth pressure, but also the following topical questions:

- What effects do the live traffic loads in accordance with DIN Technical Report 101 have, and what is the effect of overtaking HGVs in case of close passing?
- Where is the definitive proof point (pipe crown or pipe sole)?
- What influence does the carriageway surfacing have?
- What happens at and around the carriageway edges, and points of carriageway damage?
- What different load-bearing actions do rigid, flexible and profiled pipes have in the longitudinal direction?
- How should the stability of damaged pipes be assessed?

The aim is, in addition, calibration of an FEM model for the purpose of investigation of further load cases and installation situations.

Test apparatus at the IKT large-scale test facility

ND 700 pipe strings consisting of various pipe materials were installed at the IKT large-scale test facility. In addition to concrete pipes with a base, ductile cast-iron pipes of pressure level PN6 which, to permit the application of strain gauges, had no internal cement-mortar lining and no external corrosion-protection system, were also used. In addition, a further pipe string consisting of profiled PE pipes was installed after removal of the cast-iron pipe string, see Figure 3.

Soil

A sand/gravel mixture with a particle-size of 0/8 mm (Rhine sand) was used as the soil material. Rhine sand is consistently delivered by a supplier from a selected sand/gravel pit, signifying that the soil installed in the test facility exhibited virtually the same material properties at all levels. The soil was installed in accordance with the requirements of ATV-DVWK code A 139 [7], taking account of Compressibility Class V1, with compaction tests performed by the Leibniz University of Hanover; a mean degree of compaction of 95% Proctor density was determined here.

The selection of the soil material, and soil and pipe installation with careful gusset compaction, creates a typical situation for installation of pipes with shallow cover under roadways.

Diverging installation cases are to be examined by means of a Finite Element model and the reduction factors provided in ATV code A 127.

Pipes and manhole-shafts

A pipe string was installed in the longitudinal direction of the test facility for every pipe material, see Figure 4. The cast-iron and concrete pipe strings consisted in each case of six pipes and a starting, center and end manhole-shaft. In addition, a plastic pipe string consisting of three pipes and a starting and end shaft was also installed. The constructions between the manhole-shafts consist of a long center section and two short flexibly jointed elements.

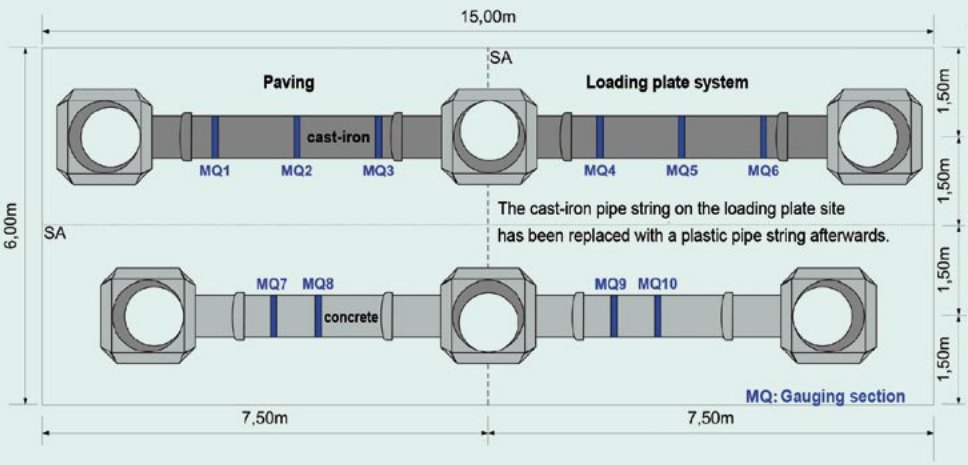


Figure 4: Basic test structure at the IKT large-scale test facility

Road pavement

A paved surface was selected as the road pavement for the cast-iron and concrete pipe strings, and for all pipe materials, a steel-plate structure, which made it possible to simulate various road pavements. Both road pavements were designed for a cover of approx. 80 cm above the pipe crown.

Paved surface

On the basis on [8], a surface consisting of rectangular concrete paving stones of Construction Class III in accordance with RStO 01 [Ordinance on highway structure, see 9] was selected as a representative paved surface. The paved surface was installed across the entire width in one half of the large-scale test facility, between the starting and center shaft of the cast-iron and concrete pipe strings. The paving work was performed by a specialist company in accordance with „TL Pflaster-StB 06" [official code for performance of road paving work, see 10]. The rectangular concrete paving stone selected, of dimensions 20 x 10 x 10 cm, was installed on a surface of around 24 m² in stretcher bond, on a gravel/sand layer of 42 cm, a gravel sub-base course of 25 cm and a 3 cm thick paving bed consisting of crushed rock. The side rows of paving was set in a mortar bed of Strength Class C12/15, and the joints then completely grouted.

Load-plate structure

A load-plate structure was selected for the other half of the large-scale test facility, in order to permit simulation of various road pavement types. The structure, consisting of one or of two steel plates, was used to generate stress states on the subgrade corresponding to those found in real carriageway surfaces consisting of bitumen and concrete. The equivalent stress values at the subgrade level were determined at the Department of Highway Engineering of the Ruhr University, Bochum, for various construction classes and carriageway surfaces, and used for specification of plate dimensions [8]. Mathematical cover depths including road pavement of 80 and 88 cm result for installation of the gravel/sand mixture up to 66 cm above the pipe crown and the use of one or two steel plates.

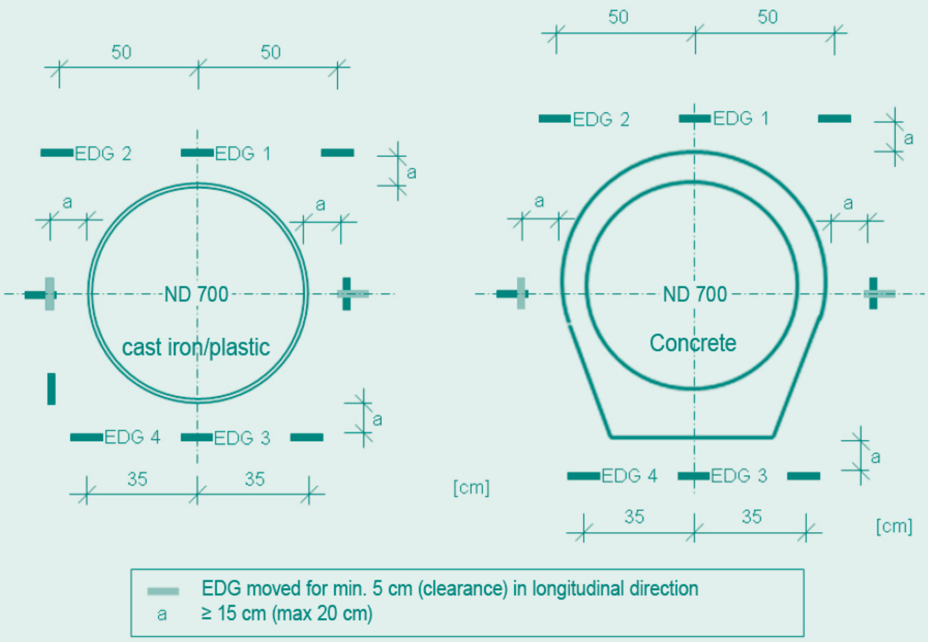


Figure 6: Location of the earth pressure transducers in the main gauging sections

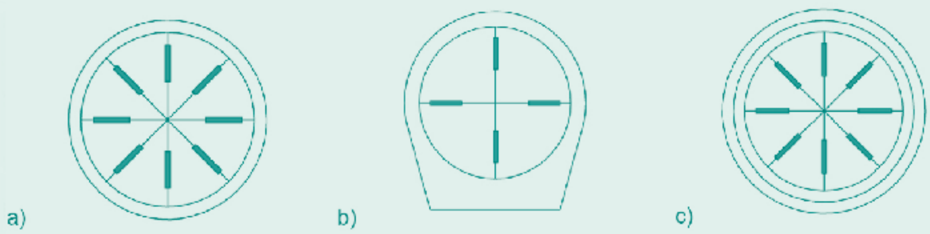


Figure 7: Location of position transducers in the main gauging sections in the a) cast-iron, b) concrete and c) plastic pipe string (measurement in the horizontal and vertical directions only at the subsidiary gauging sections)

Measuring system

Several gauging sections featuring sensors for measurement of significant soil and pipe stresses, and also pipe deformations and movements, were set up in the pipe strings shown in Figure 4. The main gauging sections MQ2, MQ5, MQ8, MQ10 and MQ12 were located at the center point of the center pipes of the pipe constructions, viewed in the longitudinal direction of the pipes. Subsidiary gauging sections MQ1, MQ3, MQ4 and MQ6 in the cast-iron pipe string, MQ7 and MQ9 in the concrete pipe string, and MQ11 and MQ13 in the plastic pipe string were positioned at the tapered end or on the socket in the boundary zones of the measuring pipes.

The main gauging sections were equipped with strain gauges, earth pressure transducers and position transducers. Figures 5 to 7 show the number and positioning of the measuring equipment described above in the main gauging sections of the cast-iron, concrete and plastic pipe strings.

Due to the profiling of its external surface, strain gauges were installed only on the inner side of the pipe in the case of the plastic pipe string. In

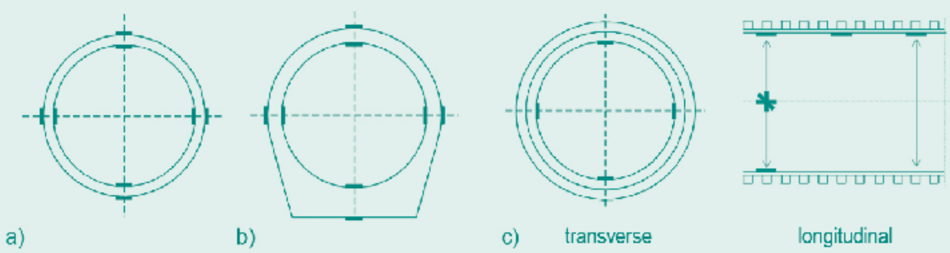


Figure 5: Location of strain gauges (axial, radial and diagonal in each case) in the main gauging sections in the a) cast-iron, b) concrete and c) plastic pipe string

addition, further strain gauges were applied in the longitudinal direction of the pipe crown, see Figure 5c. Position transducers were installed in all the subsidiary gauging sections, and pressure-measurement films on the outer side in MQ1 and MQ6 in the cast-iron pipe string, in addition.

Eight position transducers were installed in the main gauging sections of the cast-iron and plastic pipe strings, and four position transducers in all other gauging sections, see Figure 7. The position transducers were installed on aluminium measuring bridges, which were fixed in the adjacent manhole-shafts, see Figure 8.

Performance of tests

Static and load-cycle tests were performed on the test apparatus described above and the dimensioning-relevant variables measured and recorded, in order to determine the behaviour of shallowly covered pipes under live traffic loads:

- Load case: Single wheel, static
- Load case: Single wheel, load-cycles
- Load case: Wheel group, static
- Load case: Installation state
- Load case: Edge pressure
- Supplementary tests

Round 30 mm thick steel plates of a diameter of 0.44 m, bearing rubber pads, were installed under the hydraulic presses.

Load case: Single wheel, static

For the „Single wheel, static" (Z) load case, a single hydraulic cylinder was positioned centrally over the respective main gauging sections of the three pipe strings. Two load plates were laid one on the other over the cast-iron and concrete pipe strings in order to simulate a carriageway pavement of approx. 22 cm. One steel plate is equivalent to an asphalt thickness of 14 cm. The „Single-wheel, static" load case was investigated on the plastic pipe string both with one and with two load plates. In each individual test on the paved and the load-plate side, three different load levels of 60 kN, 90 kN and 120 kN were set, and maintained for a period of 30 minutes.

Load case: Single wheel, load-cycles

The „Single wheel, load-cycles" (D) tests were performed with a hydraulic cylinder on the paved and the load-plate side above the

Figure 8: Installation of position transducer assembly
above: Installation of a measuring bloc on the measuring bridge
below: Positioning of a measuring bloc in the pipe

cast-iron and the concrete pipe string; no cyclical loads were applied above the plastic pipe string. The hydraulic cylinder and load plates were arranged for this purpose in the same way as in the „Single-wheel, static" load case, i.e., centrally above the appurtenant main gauging sections. The load-cycle tests were performed to 106 load cycles at a frequency of 3 Hz, for a test period of around four days in each case. 90 kN and 20 kN were adjusted as the maximum and minimum loads.

Load case: wheel group, static

The „Wheel group, static" tests were performed using four hydraulic cylinders on the paved and load-plate side above the cast-iron and the concrete pipe string and above the plastic pipe string, see Figure 9. In these tests, the four hydraulic cylinders simulate the static wheel loads generated by a twin axle in accordance with DIN Technical Report 101. The four possible load positions of „normal „ (NL), „eccentric" (XL), „narrow longitudinal" (ELL) and „narrow transverse" (ELQ) were investigated for simulation of differing load situations. The load positions differed in the spacing of the wheel loads in the longitudinal and transverse direction and in the number of cylinders used. The wheel-load

Figure 9: Load transmission for the „Wheel group, static" load case

spacings were specified with reference to DIN Technical Report 101 [6], see Figure 10.

As previously, three different load magnitudes of 60 kN, 90 kN and 120 kN, were adjusted for all load positions and maintained for a period of 30 minutes. In order to vary the road pavement, the tests were performed in a number of cases both with one and with two stacked steel plates on the loading-plate side. In addition, selected load positions of the „Wheel group, static" load case were also investigated on the loading-plate side for two shallower cover depths of h = 68 /h = 60 cm and h = 48 cm/h = 40 cm above the cast-iron and the concrete pipe strings.

Load case: Installation state

For simulation of pipe loading in installation states, the paving on the paved side, and/or the loading plates, were removed and static forces transmitted into the soil by means of a single cylinder. The hydraulic cylinder was positioned centrally above the main gauging sections of the pipe string. A round steel plate of 830 mm diameter and 115 mm thickness was used for load transmission. Forces of 60 kN, 90 kN and 120 kN were again transmitted into the soil and maintained for a period of 30 minutes.

Load case: Edge pressure

The load case: Edge pressure (KP) was examined for the cast-iron and concrete pipe strings for Cover h = 40 cm, and for the plastic pipe string, see the „Damaged carriageway surface" section. Unlike the preceding tests for the „Wheel group, static" load case, here two hydraulic cylinders located 700 mm apart in the longitudinal direc-

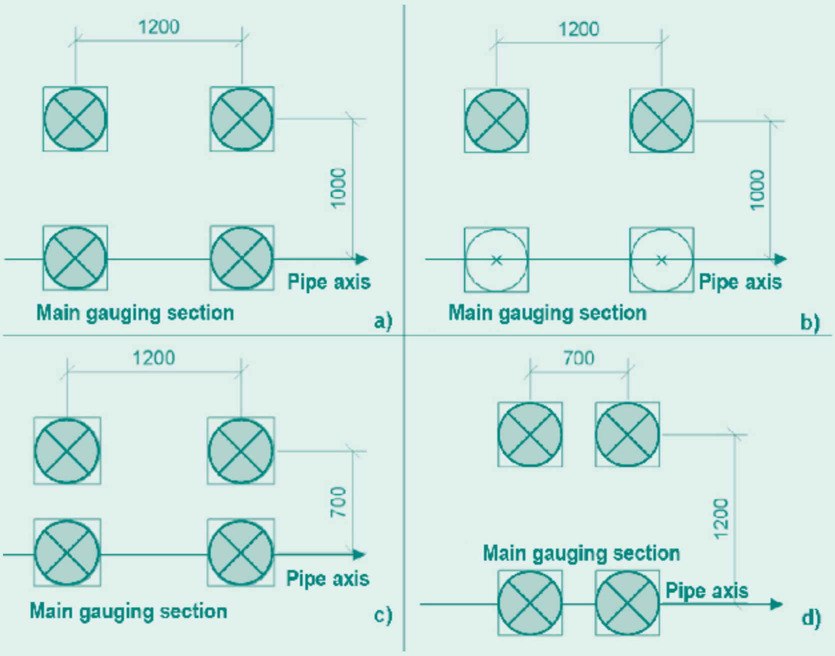


Figure 10: Load positions for the „Wheel group, static" load case:
a) NL = normal, b) XL = eccentric, c) ELL = narrow longitudinal, d) ELQ = narrow transverse

tion of the pipes were used. A steel plate was positioned for this purpose in the transverse direction above each pipe string in such a way that the load-transmission structure consisting of a rubber mat and a steel plate was flush with the edge of the plate above the main gauging section.

Further tests on the plastic pipe string

Supplementary static tests for a period of 40 hours, and also tests with sudden application of the load, were performed, in order also to obtain information on creep behaviour and behaviour under dynamic loads.

In order to verify the indication accuracy of the strain gauges used, additional vertical compression tests were performed on sections consisting of all the pipe materials after removal of the pipe strings from the large-scale test facility.

Evaluation of test results

Pipe stresses

Figure 11 shows by way of example the crown and sole stresses for the cast-iron pipe throughout the entire test period; it is apparent that the stresses do not decline to zero after each load-application/load removal test cycle, but instead continue to rise. This can be explained by soil-mechanical effects, such as trapping between the soil and the pipe surface resulting from the application of load, for example.

According to ATV-DVWK code A 127 [2], the pipe sole is in all cases definitive in calculations for a sand/gravel bed with an angle of repose of $2\alpha < 180°$. In shallowly covered pipes, however, the pipe crown is subjected throughout the test duration to significantly higher loadings than the sole, see Figure 11. Maximum pipe stresses occur in the „edge pressure" load case.

Influence of transverse traffic-induced earth pressure

The supporting transverse traffic-induced earth pressure $q_h(p_V)$ acting in the side zone is taken into account in various European standards, but not, up to now, in ATV code A 127 [2]. This transverse pressure can be estimated using the following equations:

Case 1: $(h + 0{,}4) / d_a \geq 1 \longrightarrow q_h(p_V) = 0$ (1a)

Case 2: $(h + 0{,}4) / d_a \geq 2 \longrightarrow q_h(p_V) = K_2 \cdot p_{V,K}$ (1b)

in which $p_{V,K}$ = vertical traffic-induced soil stress adjacent to pipe side zones

Intermediate values are linearly interpolated:

$q_h(p_V) = K_2 \cdot p_{V,K} \cdot f$ in which $f = (h + 0{,}4 - d_a) / d_a$ (1c)

The limiting case in Equation (1a) is defined by the fact that radiation of the quadratic wheel load reaches the outer diameter of the pipe at side length a = 0.4 m in the pipe crown, see Figure 1, center view.

In Table 1, vertical soil stress $p_{V,K}$ at the level of Side Zone K_1 is determined, in accordance with Figure 12, using the load distribution model. Horizontal soil stress $q_h(p_V)$ is then calculated using coefficient of earth pressure $K_2 = 0.4$ for non-cohesive soil, see Table 2.

The horizontal soil stresses $\sigma_{h,K}$ measured in the test are above the values determined in accordance with Equations (1a-c), i.e., the assumption for traffic-induced transverse earth pressure is on the safe side. Transverse earth pressures were, in fact, still measured in the IKT large-scale test facility at minimum cover, corresponding to Case 1 in accordance with Equation (1a).

The influence of carriageway surfacing

Undamaged carriageway surfacing

Carriageway surfaces in the form of asphalt decks of Construction Classes III and V as per RstO 01 [9] were simulated by means of one steel plate of dimensions 3.4 m x 3.0 m, and by means of two steel plates of dimensions 3.4 m x 3.0 m and 3.0 m x 2.0 m, with a thickness, in each case, of 30 mm. A reduction in vertical earth pressure compared to the calculated values was observed above both the concrete and cast-iron pipes. This decrease was larger in the case of the flexible cast-iron pipes than in the case of the concrete pipe.

The test with a paved surface indicated the greatest soil stresses, a fact which can be attributed to the low bonding of the paving stones and the absence of any load distribution by the paving. Calculated cover depth h should therefore be reduced by the thickness of the paved layer for calculation of p_V.

During installation, a layer of gravel ballast is frequently laid over the pipe, and there is, in some cases, a total lack of surfacing of the site access routes. The appurtenant loading tests without steel plates also resulted in higher measured data.

Damaged carriageway surfaces

Hydraulic cylinders (pressure-application cylinders) were positioned, as a special case, extremely close to the edge of the steel plate in the IKT large-scale test facility (the „edge pressure" load case). This, in practice, makes it possible to simulate, for instance, the transition

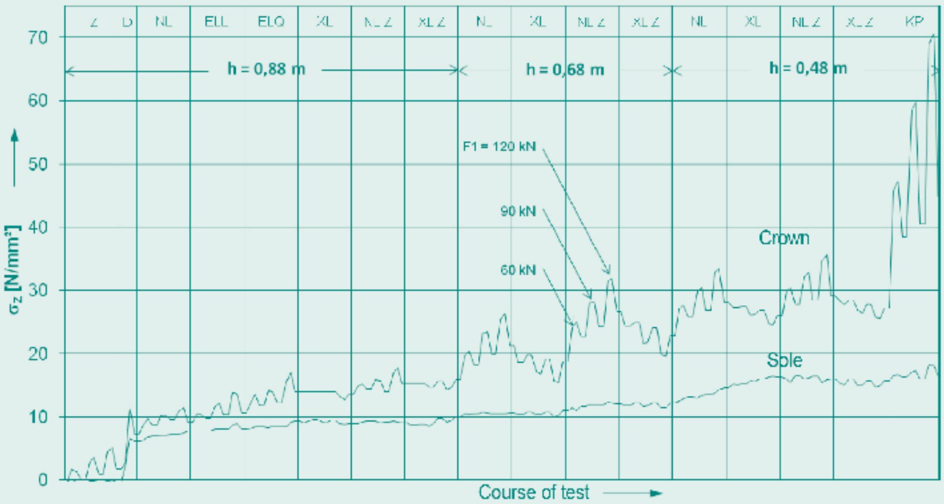


Figure 11: Circumferential stresses in the ductile cast-iron ND 700 pipe at various cover depths h, Test sequence: NL = normal load position (see Figure 2),
Z = central,
D = load-cycles (N = 10^6),
ELL = narrow longitudinal passage,
ELQ = narrow transverse passage,
XL = eccentric, KP = edge pressure,
Addition Z: Construction Class V as per [9] (one steel plate)

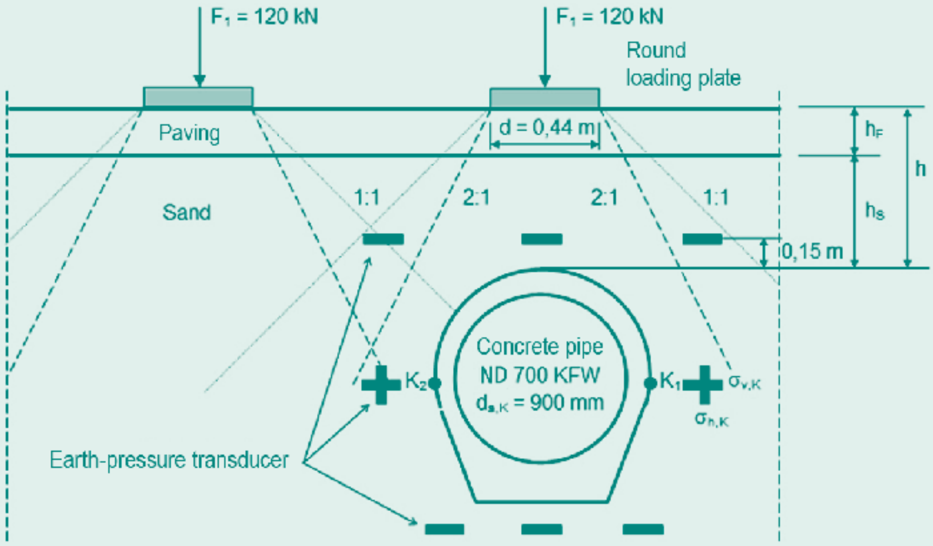


Figure 12: Spread of load over the ND 700 concrete pipe KFW, normal load position (to scale for h = 0.88 m)

Table 1: Vertical soil stress in the side zone of the concrete pipe, d_a = 0.93 m

h	$h_K = h + 0.465$	$b_m = l_m = h_K + 0.4$	$A_m = b_m \cdot lm$	$p_{V,K} = F_1/A_m$
m	m	m	m²	kN/m²
0.88	1.345	1.745	3.04	39.5
0.68	1.145	1.545	2.39	50.2
0.48	0.945	1.345	1.81	66.3

Table 2: Horizontal soil stresses in the side zone of the concrete pipe, d_a = 0.93 m

h	Eq. (1a): $(h + 0.4)/d_a$	Eq. (1c): f	Tab. 1: $p_{V,K}$	Eq. (1c): $q_h(p_V) = K_2 \cdot p_{V,K} \cdot f$	Measured value $\sigma_{v,K}$	Measured value $\sigma_{h,K}$
m	-	-	kN/m²	kN/m²	kN/m²	kN/m²
0.88	1.38 > 1	0.376	39.5	**5.94**	13.7	**6.0**
0.68	1.16 > 1	0.161	50.2	**3.23**	16.3	**4.7**
0.48	0.95 < 1	0	66.3	**0**	16.5	**7.0**

zone from concrete-surfaced carriageways to other carriageway surface types, or a transverse crack in the road surface, see Figure 13. Here, the live traffic loads are no longer transmitted uniformly into the subgrade but, instead, approximately triangularly, see Figure 14.

The „edge pressure" load case results in significantly greater soil stresses and pipe stresses compared to the normal load position in accordance with DIN Technical Report 101 [6]. The soil stresses above the crown of the concrete pipe are greater by a factor of 2.9 compared to the normal load position. This factor is, in fact, 4.2 over the cast-iron pipe. A considerably increased load on buried pipes must therefore be anticipated in case of damaged road surfaces and in the vicinity of transitions in carriageway surfaces, if no provision to assure transmission of transverse forces is implemented.

Longitudinal load-bearing action of pipes

Figure 15 shows the changes in diameter of the two flexible pipes for normal load position in accordance with DIN Technical Report 101. The deformations of the profiled wound PE pipe have a lesser extent in the longitudinal direction of the pipe than those in the ductile cast-iron pipe. This can be explained by the load-bearing action as an orthotropic shell, which takes place primarily in the circumferential direction.

The deformations in the longitudinal direction also include longitudinal stresses, however, which are generally not taken into account in pipe-statics calculations. The aim of this research project is, therefore, also the development of a simple, calibrated computation model of three-dimensional load-bearing action, e.g., the flexibly bedded beam.

Load transmission in the longitudinal direction is not possible in the case of short pipes and pipes

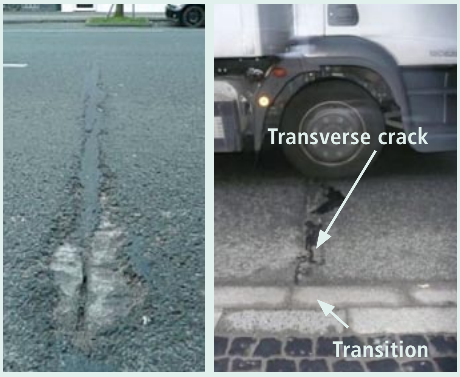


Figure 13: The „edge pressure" (KP) load case with a transverse crack in the road surface, transition between various carriageway structures

with transverse cracks. An increase in the live traffic loads is necessary in such cases.

Calibration of the FEM model

A three-dimensional Finite Element model is generated using the ABAQUS program to permit comparative assessment of numerical models against the test results and for investigation of further load cases, see Figure 16, with cross-linking and pipe stresses.

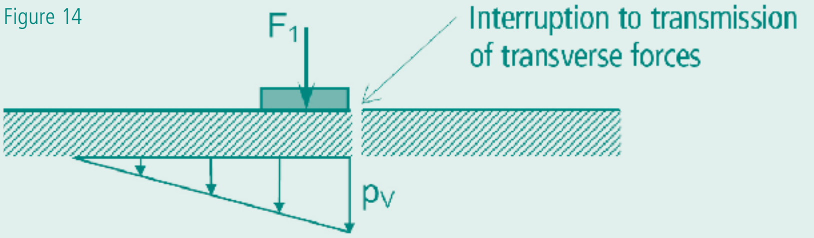
A linear-elastic materials law suffices for simulation of the asphalt surface course in the case of the steel plates, while computations using an elastic and, additionally, a plastic law in accordance with Mohr-Coulomb are performed for the soil. Transmission of tensile stresses between the steel plate and the soil and between the soil and the pipe is prevented by means of contact elements. Symmetry conditions are assumed for modeling, see Figure 16.

The calculations in accordance with the A 127 code and the FE model supply significantly higher pipe stresses for h = 0.88 m than the data measured for normal load position in the IKT large-scale test facility, see Figure 7. The edge pressure load case is also included as the „worst case", the transmitted pipe stresses σ_φ apply in case of a shallower cover (h = 0.40 m) and Construction Class V, however.

Summary

Tests on buried concrete, cast-iron and PE pipes embedded at a shallow depth, with load configurations in accordance with DIN Technical Report 101 [6] are reported. The soil stresses in the vicinity of the pipe, the pipe stresses in the

Figure 14



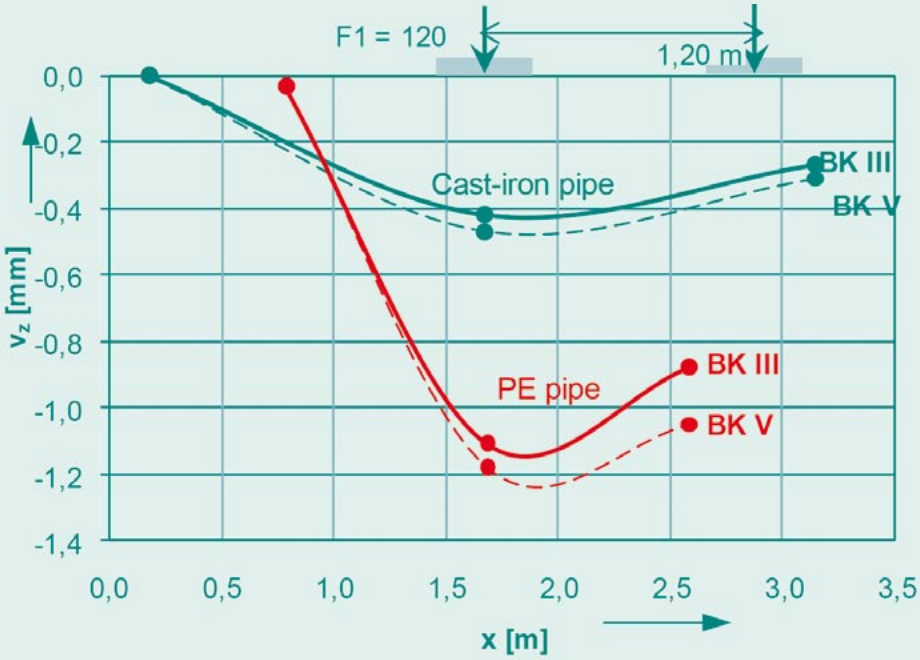


Figure 15: Plot of pipe deformations in the longitudinal direction for the normal load position (NL), for Construction Class III and V carriageways

crown, the side zones and the sole, and the pipe deformations, are evaluated.

Accordance is good in the case of the soil stresses, but the pipe deformations and stresses are generally lower than indicated by the calculation methods used up to now (ATV code A 127 [2], TR 1295, Part 3 [11] and the Finite Element Method).

Only the circumferential stresses are determined in ATV A 127 and TR 1295, Part 3, however, the stresses in the longitudinal direction of the pipe and the shear stresses, which are both also important in the case of shallow cover depths, are not taken into account; here, the tests provide approaches for the improvement of the computation models (e.g. the model of the elastically bedded beam).

A development against time (in this case: increase) of the pipe stresses is indicated for all pipe materials, i.e., the values measured do not decline toward zero after removal of the load on a test section and repositioning of the loading apparatus. The resultant ultimate stress can therefore be considered to be the result of a „loading history".

The pipe materials investigated exhibit differing longitudinal load-bearing actions, the lowest being that of the profiled plastic pipes. Interruption of the longitudinal load-bearing action as a result, for instance, of a transverse crack in damaged pipes can be taken into account by means of higher mathematical crown loadings.

Tests performed using cyclical loads at 75% of maximum load (F_1 = 90 kN) and 106 load cycles result in a significant increase in soil stresses and a slight increase in soil compaction.

Close passage of a vehicle specified by the loading diagrams in DIN Technical Report 101, damaged carriageways and transition points in carriageway surface type result in increased loads which, in some cases, are covered by the dimensioning standards used up to now.

Other tests investigated the impact factor in the case, for example, of damaged carriageway surfaces, which was 1.2 to 1.5 in the preceding standard, and is included in the live traffic loads in accordance with [6]. Dynamic reactions of the pipe/soil system in case of sudden load application over the concrete pipe and the plastic pipe are also compared.

The results of this research project will, in future, permit more accurate dimensioning of shallowly covered pipelines below various roadway surfaces and during installation. They will be used in the revision of the body of rules for the calculation of buried waste-water conduits and pipes (ATV A 127).

It is thus now possible to better estimate the load exerted on damaged pipes with only shallow cover. The concept for concentrated area loads (vertical earth pressure and supporting lateral pressure) is, in addition, to be incorporated into the dimensioning of repair systems for Old Pipe Condition III.

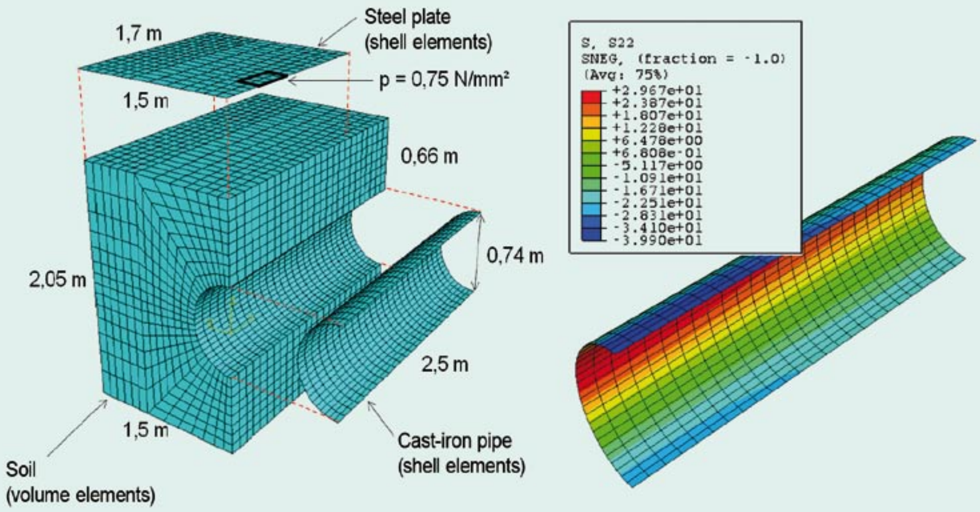


Figure 16: Three-dimensional FE model, circumferential stresses on the outer side of the ND 700 cast-iron pipe, h = 0.88 m, load position NL, Construction Class III asphalt carriageway

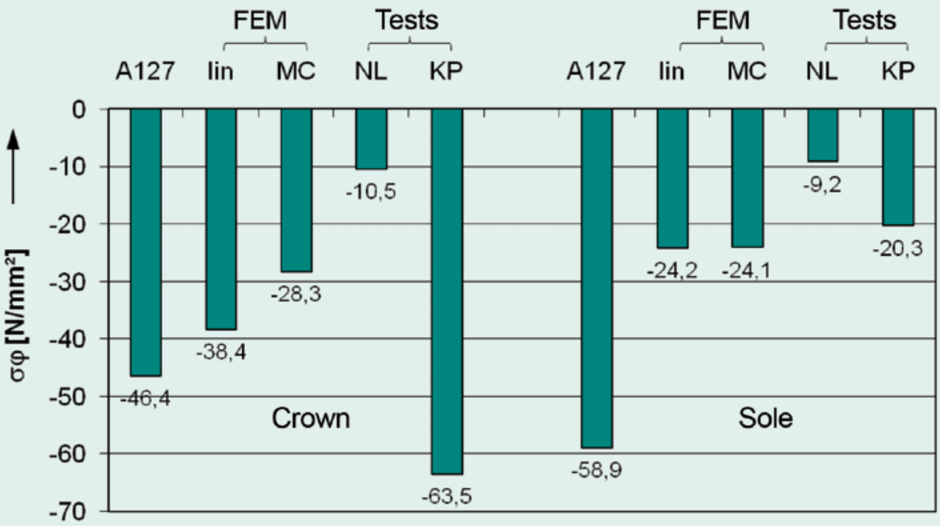


Figure 17: Circumferential stresses on the cast-iron pipe, sources: A 127 code, Finite Element Method (lin = linear soil law, MC = Mohr-Coulomb), tests: normal load position (NL) in accordance with Figure 2 at h = 0.88 m and Construction Class III, edge pressure (KP) at h = 0.40 m and Construction Class V

Authors
Prof. Dr.-Ing. Bernhard Falter,
Dipl.-Ing. Martin Wolters,
Univerity of Applied Sciences Münster

Dr.-Ing. Bert Bosseler,
Dipl.-Ing. Bianca Diburg,
Dipl.-Ing. Martin Liebscher,
IKT - Institute for Underground Infrastructure

References

[1] Falter, B.; Wolters, M.: Mindestüberdeckung und Belastungsansätze für flach überdeckte Abwasserkanäle (MIBAK). Research project IV-9-042 3E1, subsidized by MUNLV. Concluding Report dated December 19, 2008
[2] ATV-DVWK code A 127 (2000): Statische Berechnung von Abwasserkanälen und -leitungen, 3rd edition, Hennef.
[3] Steffens, K. (Ed.); Falter, B.; Grunwald, G.; Harder, H. (2002): Abwasserkanäle und -leitungen, Statik bei der Substanzerhaltung und Renovierung (ASSUR). Cooperative Research Project 01RA 9803/8, subsidized by BMBF. Concluding Report, Eigenverlag Inst. für Experimentelle Statik, Hochschule Bremen.
[4] Bundesministeriums für Verkehr, Bau und Stadtentwicklung (2001): Verkehrsprognose 2015 für die Bundesverkehrswegeplanung [BMVBS] (FE-Nr. 96.578/1999). Concluding Report, April, 2001.
[5] Hornung, K. (1984): Straßenverkehrsbelastung erdüberdeckter Rohre. Korrespondenz Abwasser 31 532-541.
[6] DIN Technical Report 101: Einwirkungen auf Brücken, 2nd edition, March, 2003, Beuth Verlag.
[7] ATV-DVWK code A 139: Einbau und Prüfung von Abwasserleitungen und -kanälen; June, 2001, Hennef.
[8] Radenberg, M.: Gutachterliche Stellungnahme zur Auswahl und Verlegung eines Pflasterbelages, Bochum 2007 (not yet published).
[9] RStO 01 (2001): Richtlinien für die Standardisierung des Oberbaues von Verkehrsflächen.
[10] TL Pflaster-StB 06 (2006 edition): Technische Lieferbedingungen für Bauprodukte zur Herstellung von Pflasterdecken, Plattenbelägen und Einfassungen
[11] TR 1295, Part 3 (2006): Structural design of buried pipelines under various conditions of loading – Part 3: Common method.

Functions of bedding and filling materials

Installation of the layer of coarse grain 100-150 mm, from [2]

Bedding and filling materials in the sewage and pipeline construction should substantially contribute to structural stability of the building. In measures for rainwater retention and vegetation design, filling materials with special characteristics are used. Experience from research and pilot projects with these application cases, possible conflicts as well as new bedding and filling materials now show perspectives how different utilizations and material functions in the pipeline trench can be mutually supplemented.

Introduction

Bedding and filling materials are used in the sewage and pipeline construction in order to substantially contribute to the structural stability of the underground building and where appropriate to the building on the street, as part of the pipe/ground structural support system. In general, the characteristics of filling materials in the city structural formation with view of water economic aspects and the arrangement of tree locations are of greater importance. Under congested conditions, conflicts can also occur in the ground, for example, from the interaction of tree roots with underground sewage system and pipelines.

With this background, the question is, which role does the bedding and filling materials as a building element of the classic pipeline trench play individually, which innovative materials in this context are researched to-date and used in practice, and which perspectives arise for combined requirements and utilizations of the used materials in the pipeline trench. The following versions give an overview based on the project experience at the IKT - Institute for Underground Infrastructure, Gelsenkirchen.

City planning

In city planning, the use of bedding and filling materials, especially in the course of decentralised storage and infiltration of rainwater is becoming important. Corresponding measures influence the following, among other things (cf. [1]):

- the drain dynamics within and beneath a settlement zone,
- the new ground water formation,
- the municipal water and its ecological condition

Just in densely populated cities with high sealing degrees and intensive utilization of the surfaces and underground space, appropriate measures can only be implemented in isolation rarely or not at all. It is therefore opportune to combine possible zones for the storage and infiltration of rainwater with elements of vegetation planning and especially with planting pits of trees in this case.

In Stockholm, for example, trees planting pits are used for rainwater farming, and tree irrigation occurs simultaneously [2]. The planting pits were executed there with an expanded rhizosphere. In the specific case, the rhizosphere was constructed graduated and has an entire height of ca. 1.0 m. The lower layer consists of broken material - grain sizes 100 to 150 mm - with a layer thickness of 600 mm.

Above, a layer approx. 180 mm strong with broken material of grain size 63 to 90 mm is incorporated. In both of these, a small share of fine earth is flushed on layer that is rich in coarse pores, especially to improve the water retention. In the next step, a partition fleece is put in place and crushed rock is poured to make a formation for laying the sidewalk slabs, paving stones, or asphalt. All layers are respectively compacted. The provision of rhizosphere with air and water occurs through a special ventilation and irrigation component that penetrates a depth of approx. 80 cm into the rhizosphere. A street gully is placed on the stainless steel element that forms the termination to the pavement or asphalt surface.

Figure 1 and 2 give an impression of the situation on the spot: After conclusion of the project, the surface will be restored. The rhizosphere created underground is then no longer recognizable and the surface can be used without restrictions [2]. The result must ensure that actual irrigation is provided without rewetting risks and oxygen deficiency for the plants. In strongly compacted grounds, rainwater is transmitted away where appropriate.

Tree roots and pipelines

The conditions of life of city trees were investigated comprehensively in the past decades. The volume of root system must stand in a well-balanced relationship to the volume of the crowns. A rhizosphere that is too small generally

Figure 1 (left) Installation of the layer of coarse grain 100-150 mm, from [2]
Figure 2 (above) Condensation of coarse grain layer with usual compaction equipment, from [2]

has diminished growth of aboveground parts of the tree as consequence [3].

The pore space in the ground has essential influence on root growth. Roots serve for the up-take of nutrients and water from the soil. They should in addition anchor the plant in the ground. Unhindered root growth occurs in large pores. At the same time, it is assumed that roots can penetrate in pores of diameters greater than 0.2 to 0.4 mm [4], [5]. Fine pores are occupied by root hairs. In order that the organism can further cover its need for nutrient and water over its entire life, also the root system grows further and steadily opens itself new ground space. At the same time, roots, like all plant parts, depend on functioning respiration (oxidation) carbohydrate rich connections for energy generation. Necessary oxygen is found in natural soil structure in soil air and can be absorbed by roots. Low oxygen contents in soil air are described as a trigger for growth depression ([6], [7].

From vegetation point of view, especially requirements are made on substrates for planting of trees with respect to (cf. [8], [9]):

- grain size distribution, for example predominantly sand as well as gravel/crushed rock, supplemented with silty and clayish shares
- soil air-/soil water household, for example, with respect to water permeability kf and an entire pore volumes greater than 35%
- soil chemistry, for example, a share of organic substance smaller than 2-4 %-mass
- Load bearing capacity, for example as demands on the deformation modulus and proctor density in vegetation layers.

These requirements make it clear that with use of classic bedding and filling materials of the sewage and subsurface pipeline construction, for example gravel-sand-mixture, frequently unconsciously an especially ground that can be penetrated well by roots is created, which already fulfils essential demands on vegetation bearing layer. As consequence, roots grow from areas with poorer pore spaces of surrounding soil into the pipeline trench and follow the way of the least resistance, usually into the badly compacted gore under the pipe (Figure 3). There they can then follow the pipe surface, surround the pipe or reach a pipe connection, that offers them further space for growth, (Figure 4).

In the end, this can lead to damages to the pipelines, for example through root ingress into the pipe connection of sewage pipelines (cf. [10]). At the same time, roots can exert pressure of more than 10 bar so that they can overcome for example the contact pressure of elastomeric seals and can grow as well as into faultless pipe connections.

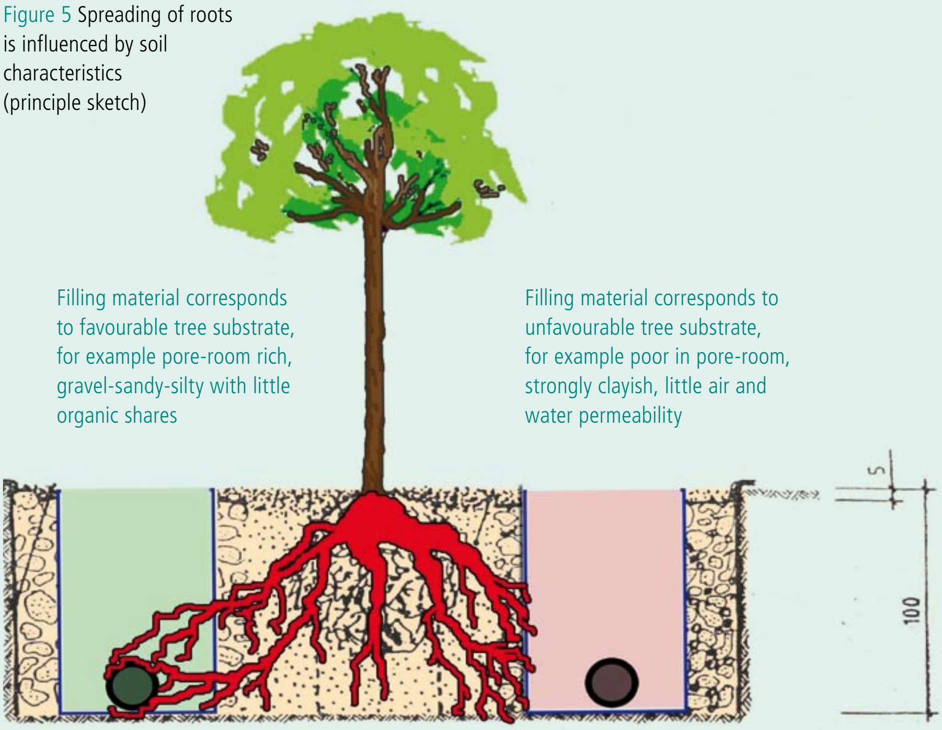
Figure 3 Roots in pipeline trench: root has grown into the sewer and in the end in weakly compacted gore area

Figure 4 Sealing element of the pipe connection of a combined sewer: Elastomeric ring is covered completely with root cushion in the crown

In the framework of the research project [10], the causes for root ingress in sewage pipelines and channels were investigated comprehensively. It was confirmed that especially in anthropogenically influenced city soil, different soil kinds are found in small space whereby the soil characteristics differently influence root growth. With view of the soil in the pipeline trench, a pore room especially too small for roots leads to a handicap and/or prevention of root growth and can be used therefore for the protection from roots (Figure 5). The use filling materials with poor pores is conceivable here, which can be brought in place both as flowable material and as a material with bentonite content and/or bulk material capable of swelling. Conversely, soil with sufficient and well-ventilated pore room is considered as plant substrate that is taken over by roots as habitat.

These contexts on the interaction behaviour between roots and different substrates are for example very clear in tests on plant boxes [11]. Roots made of poplars (Populus spec.) grow there in a plant substrate in the surrounding of an incorporated bentonite body, i.e. plastic material with high clay content. The roots grew on the boundary area - substrate/bentonite - on the substrate side along the bentonite. Individual roots grew nonetheless also into the bentonite.

Figure 5 Spreading of roots is influenced by soil characteristics (principle sketch)



Here it is assumed that swelling and shrinkage cracks in the bentonite were filled out by roots.

When tuning lacks between the requirements of civil engineering and the vegetation planning, not only pipelines but also tree roots can be damaged disproportionately. As a preventive measure, it is therefore recommended in [12], [13] especially to provide a root curtain before the start of the construction process.

Figure 6 Poplar roots and bentonite body in plant box – roots grow along the boundary area to the bentonite as well as in the bentonite body in isolated cases, from [11]

According to [13] a ditch is excavated manually in approx. 0.3 m distance from the future building project, corresponding to the root penetration depth. On the side towards the trench, all roots are cut off and the interfaces treated. Posts are installed on the trench wall towards the construction pit, then non-galvanised wire mesh is nailed on the posts and a bale cloth made of Jute is fixed on the wire. The ditch is then filled with suitable substrate. Here the direct question is to what extent by this action is just the ingrowth of roots into the pipeline trench just facilitated. Certainly, this depends again on the characteristics of used bedding and filling materials. Which role do these materials as building elements of the structural support system pipe/soil play, is therefore supposed to be clarified as follows.

Structural support system pipe/soil

If sewage pipes are incorporated in open method of construction, the so-emerging structural support system pipe/soil can be described for circular round pipes according to Figure 7. The cross-section view corresponds to that for earth-laid sewers and pipelines according to [14] usual assumption of uniform bedding- and deformation characteristics in longitudinal direction. The interactions between pipe, imbedding, trench filling, and surrounding soil can then be attributed to five-model assumption:

1. The theory of silo effect for soil load calculation in pipe crown height goes back to the investigations of Janssen [15], Terzaghi [16], and Marstone [17]. According to this model assumption, slide and/or shear surfaces form on the trench walls similarly to the area between bulk goods and silo walls. The resulting friction forces occurring in these shear surfaces due to settling increase or diminish the cantilever wall. The type of trench support and where appropriate the evolving „support track" gains special importance [18]. In addition, both trench walls must remain in place for activation by frictional forces and they may not be removed during subsequent material excavation of a neighbouring construction trench.

2. In case of good compaction of lateral soil next to the pipe, vertical loading by the pipe and lateral soil are carried together. The vertical load distribution over the pipe crown then depends on the rigidity of the soil in the

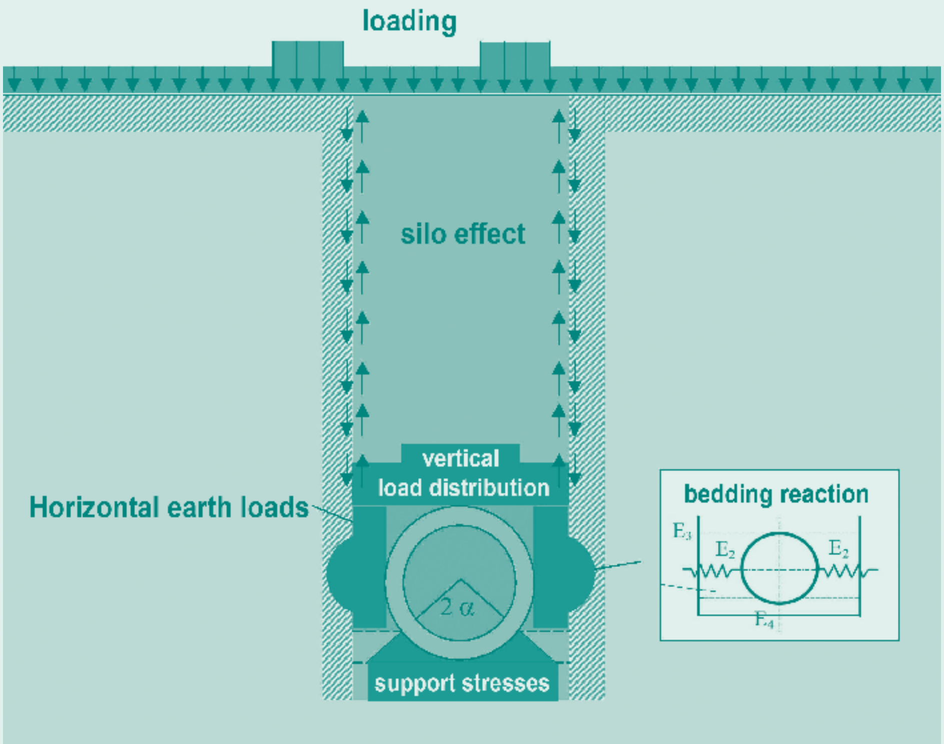


Figure 7 Pipe/soil in open method of construction, model assumptions (representation of the spring model of bedding reactions, from [14])

relationship to pipe stiffness. If the pipe is stiffer than the soil, the loads concentrate on the pipe. If the soil is stiffer than the pipe, the soil bears the greatest share of the loads. This model concept has found also input into German calculation practice (cf. [19], [14]).

3. The support stresses under the pipe sole are determined generally under the approach of a defined support angle (cf. [20], [14], [21]). The constructive erection of pipe bearing, i.e. especially compaction of the gore area under the pipe, influences structural stability of entire system.

4. Horizontal earth loads also already act on a stiff pipe, which can be applied approximately at the height of the so-called of „soil pressure at rest" (cf. [14]).

5. In larger cross-sectional deformations of flexible pipes (e.g. plastic pipes), the soil next to the pipe can unfold further supporting effect. The vertical deflection then yields a horizontal diameter enlargement through which the pipe in the soil activates a horizontal bedding reaction pressure. In addition, this approach has found entry into the calculation concept according to [14].

Especially the soil characteristics in the area of the pipeline zone influences substantially load-bearing capacity, settling behaviour, usage capacity, operational reliability, and utilization duration of underground sewage and pipelines [23]. In the pipeline zone, according to [24] granular, unbound construction materials should be used. Even hydraulically bound construction materials are acceptable as far as they correspond with the planning requirements. As granular, unbound construction materials, for example sand-gravel-mixtures with graduated graining and negligible binding shares (<3%) are considered as suitable according to [24], Supplement B, Table B4. For the application of industrially produced rock classifications and recycling (RC)-construction materials, its suitability due to mechanical soil viewpoint and environmental friendliness have to be especially proved.

According to [23], Chap. 12.4.2 the following applies specifically:
„The compaction degree in the pipeline zone and main filling must be tested. Acceptance criteria are soil characteristic values based on soil characteristic values or the requirements of ZTVE StB 94, Edition 97."

In addition, a concrete bedding as a part and full casing is listed in [23], Chap. 7, implementation possibility, when locationally different soil types, changing water levels, a strongly inclined trench sole or rock exist.

If the so described structural support system pipe/soil is supposed to be produced reliably and cost-effectively also under congested space conditions, then the direct question posed calls for procedure and material optimization possibilities, especially also with view to bedding and filling materials.

Material developments

Further development of bedding and filling materials has as construction goal, to reduce the working space necessary for the execution of uniformly well-compacted bedding of the sewer and at the same time to ensure the quality of the hardly accessible gore area. As examples for such developments, the following should be cited: Flowable self-compacting bedding and filling materials as well as bedding cushions made of expandable polystyrene (EPS).

Flowable self-compacting filling materials

These filling materials are also cited in [23] as a special procedure for the manufacture of pipeline zone and main filling with the following components: Classified non-binding mineral material or also binding material (pending trench excavation material, soil derived from elsewhere or recycling material), plastifying and stabilising additives, cement, water and where appropriate pores or foaming agent.

Figure 8 Installation of flowable self-compacting filling materials in narrow trench width

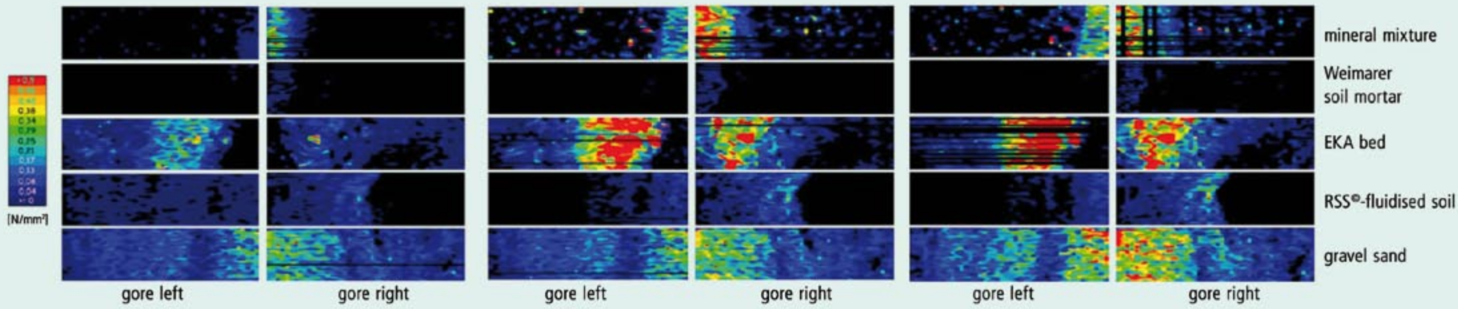


Figure 9 Contact stresses in the pipe support between soil and pipe: Installation condition (left), after pulling the bulkhead (middle) and under the load (right) - [25] bulk material: Mineral mixture, EKA bed, and gravel sand; flowable: Weimarer soil mortar and RSS©-fluidised soil

According to [23], Chap. 7 *„its suitability in a specific application case must be examined under the consideration of the interaction with naturally available soil. In this regard it is recommended to consult a specialised expert."*

Flowable self-compacting bedding- and filling materials are used especially in order to optimally fill the critical support area optimally even under congested space conditions and to obtain uniform bedding in the entire pipeline zone (Figure 8). Moreover, through the excavation work, cavities that emerge can be filled with the excavated material in order to avoid retroactive settling.

With this background, extensive large tests were carried out in the IKT, which in the end confirmed positive effect of flowable bedding and filling materials on the contact stresses between soil and pipe [25]. Tests were conducted in the scale 1:1, in which the complete loading history of a pipe was imitated from the installation via dismantling of construction elements up to traffic loads, ground water variations, and mountain declines. Clearly more uniform contact stress distributions in the support area, i.e. in the left and right gore areas between pipe and soil (Figure 9) in the result in contrast to the utilised bulk goods in the same test setup.

Experiences from accompanying in-situ-measures in the German cities Dusseldorf (cf. [26]) and Gelsenkirchen showed on the other hand also, which special risks are to be observed in the construction practice in the use of flowable bedding- and filling materials. On the one hand, the buoyancy forces emerging on the pipe must be absorbed. This is usually connected with high technical expense, e.g. through gradual filling of the pipeline zone or by using appropriate holding structures (Figure 10).

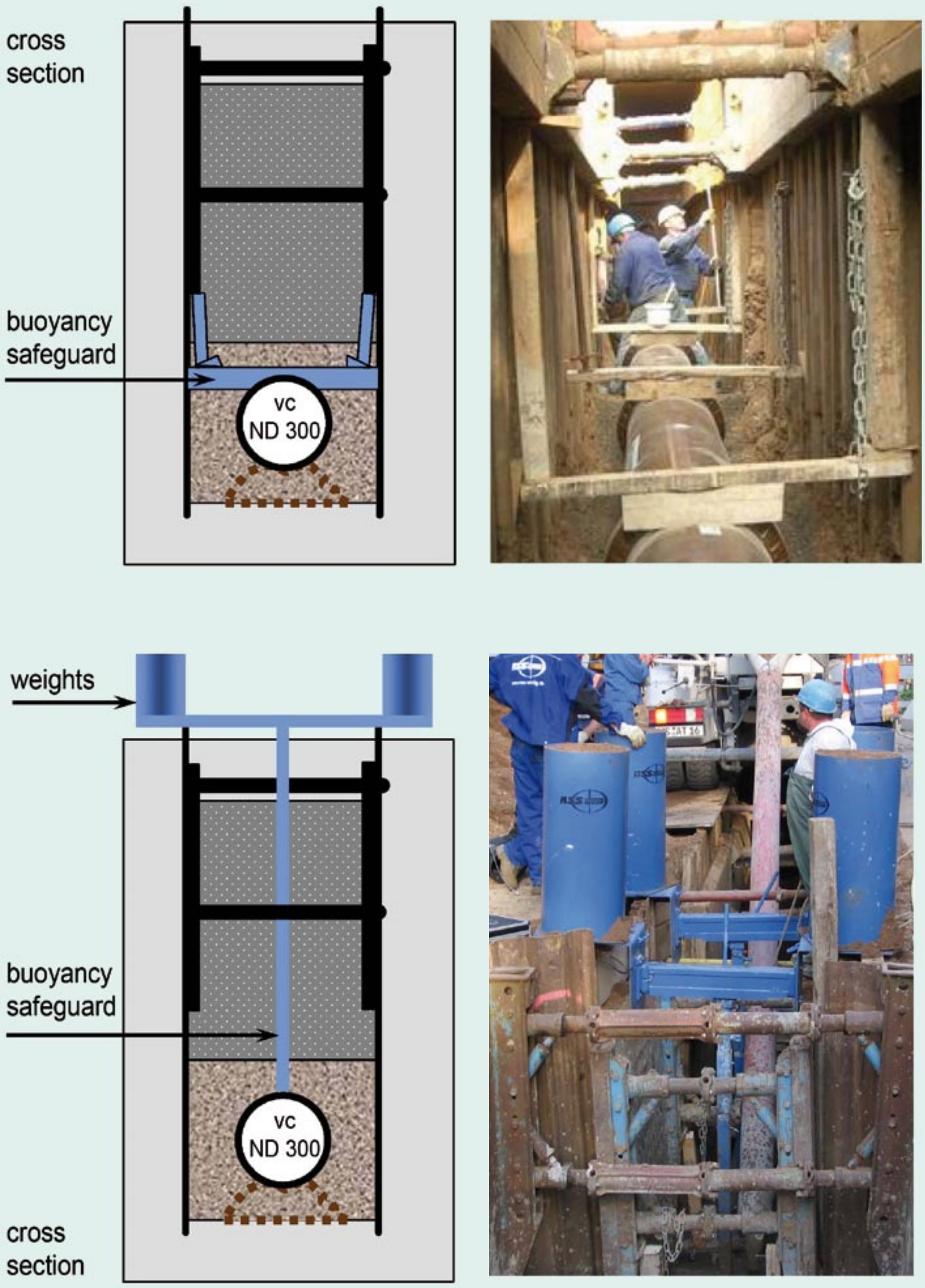


Figure 10 Examples for buoyancy safeguard: Wooden beam construction (above) and RSS© system (below)

On the other hand, in a subdivision into several construction sections, these must be partitioned and/or sealed in an appropriate manner in order to prevent uncontrolled spreading of the material. In addition, the flowing capacity of the material can also be connected with first of all unexpected quantity scope, for example, if cavities behind the construction elements are filled or water leaks into the surrounding soil.

In the scope of the quality assurance of the material characteristics, besides the flowing capacity in the installed condition, also demands on the strength, solubility, and permeability of the cured material should be formulated. The strength development and the deformation occurring during fracture should be verified in dependence on the curing time over a longer period. The long-term solubility, especially for later connection of lateral inflows, for example can be verified in modified pile-driving test (cf. [25], „spade ram“) in order to grasp also the influence of the grain distribution on the penetration behaviour of dismantling tools. If special demands were made on the permeability and/or impermeability of the material, then samples should be taken for verification in construction accompanying manner.

Bedding cushion made of EPS

These bedding cushions are used in order to execute the critical support area in earth laid sewage systems and pipelines optimally and if necessary to be able to lay even pipelines one above the other. In a research project [27], the suitability of such bedding cushions in laboratory tests and construction site application was investigated. Especially the practical applications on the construction site underlined the advantages of the system with respect to handling and installation speed (cf. Pictures 11). In addition, also tests stretches were in the meanwhile executed with EPS full casing of plastic pipes and a combination with the use of flowable filling materials discussed [28].

Usage risks exist especially with respect to the resistance of the EPS against aggressive soil ingredients as well as gasoline and oil types. In groundwater, the buoyancy of the bedding cushions must be considered in the calculation and dimensioning of the pipes and trenches.

In the framework of quality assurance attention is to be paid especially to the used quality of the EPS. Different variants are offered here, which differ essentially from one another through their density. In the project, an EPS 35, i.e. expandable polystyrene with a density of 35 kg/m^3, proved suitable for use as a pipe bedding in the sewage and pipeline construction. The density of the material can be controlled by simple measuring and weighing and a static calculation according to [14] is possible (cf. [27] in proven material behaviour and simple laying procedure. In addition, it should be noted that the cushion dimensions must be adapted especially to the respective outside diameter of used pipes. In addition, here, a random sample-like inspection is recommended.

Perspectives

The above example on city planning clarified already that by the selection of bedding and filling materials different utilization methods can be addressed simultaneously. For instance, materials with larger pore space promote both possibilities for the decentralised rainwater farming and for the rhizosphere formation as well. In addition, filling materials rich in pore space are used also in the sewer and pipeline construction owing to soil mechanics reasons, as they find application to vegetation bearing layers. Supplementary technical measures in the underground, e.g. the formation of a root curtain before trench excavation, can increase the range of consideration. Here the question is now whether the knowledge of these different utilizations also offers new perspectives for civil engineering solutions.

Based on the experiences represented in this text Figure 12 shows a suggestion for multifunctional formation of the pipeline trench. Using different bedding- and filling materials, the represented trench zones S, D, H, N, can then be attributed to different utilizations or functions. Examples are as follows:

N – Utilisation: Usually this area is dimensioned for the load transfer from road surface. At the same time, it cannot be ruled out that pore spaces of this area also allow root growth and unfold drainage effect. A scheduled utilization can clearly emphasize these connections and make the deliberate. This applies generally to the scheduled formation of a vegetation layer on which a structure can be built, as they are also recognised for other areas (cf. [9]). Nonetheless, it should also be considered that during later measures on the underground pipeline in open method of construction, this area and thus the root system must be disturbed (again). In addition, it should also be questioned whether in the case of vegetation utilization where appropriate special measures are to be planned for construction above the ground.

Figure 11 Practical application of bedding cushions: laying (top left), cutting to size on site (bottom left), complete encapsulation as a variant (right)

D – Cover layer: The cover layer jointly with the lateral filling S and the internal shearing forces in the utilisation zone N contribute to the load distribution within the pipeline zone. By using particularly materials with less pores, a layer that accordingly repels root growth can formed here. For example, if flowable, castable materials are used, also the civil engineering requirements according to [24] can be fulfilled.

S – Lateral filling: The lateral filling serves substantially for the transfer of vertical loads, especially in load distribution in this area. Well compressible materials are to be used. In the sense of root protection, it is convenient - similarly to the cover layer - also to use self-compacting materials with hardly any pores. If a rich pore-space material is used, utilization as drainage space is also considerable.

H – Cover zone: The cover zone can serve directly for pipe protection during the installation (cf. EPS- or concrete full casing). If EPS is used, also in rigid pipes, a deformation capable overall, system occurs, which can avoid vertical loads (cf. Deformation layer according to [14]).
The cover zone, where appropriate, also jointly with the zones S and D, can be filled with poor pore space material. In water protection areas, strong impervious material (cf. „mineral mixture" in [25]) can also serve for double exfiltration protection, similar to double wall pipes. The capacity of EPS for thermal insulation additionally opens a special perspective for sewage waste-heat utilization. A possibly high-energy gain could be secured in the area behind heat inputs.

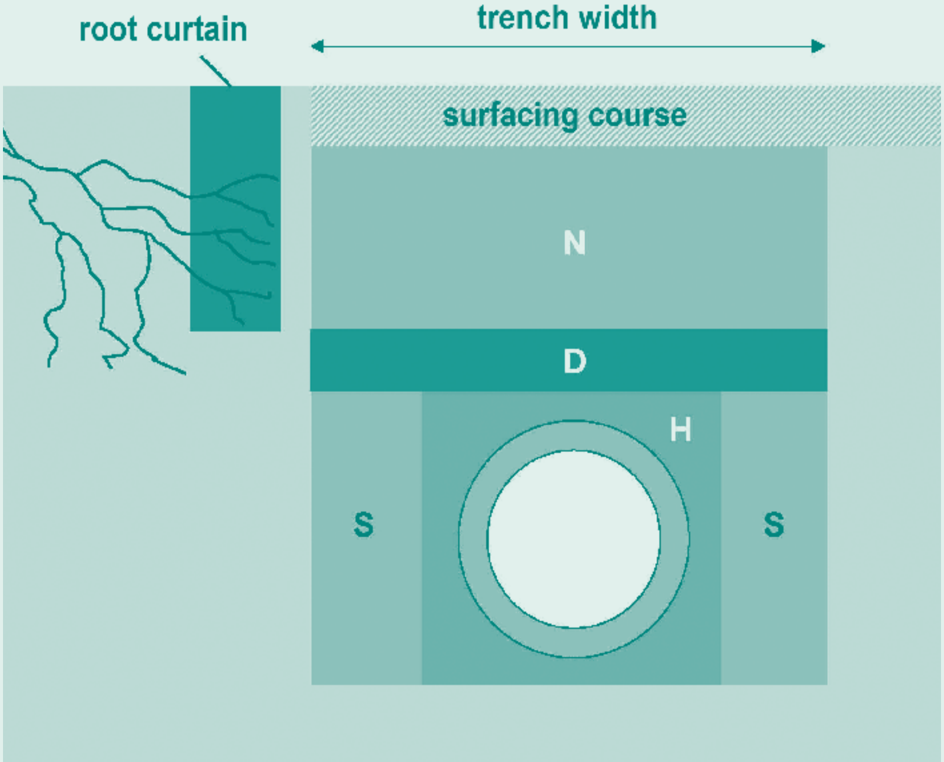


Figure 12 Pipeline trenches with multifunctional trench zones
N – Utilization, D – Cover layer, S – Lateral filling, H – Cover zone

Conclusions

Manifold requirements are put especially underground in the urban area. This concerns also questions of the water economy, vegetation planning, and other utilizations besides the constructional load-bearing capacity (e.g. waste water/soil heat). The trenches produced in open method of construction in the course of sewer and pipeline construction offer the chance to address these manifold utilizations jointly by targeted use of innovative bedding and filling materials. Advantages arise with view of the following points:

Economic viability: Construction costs can be reduced through smaller trench widths and faster construction processes and risks from root growth can be diminished through targeted use of materials with hardly any pores. Cost saving potentials would offer also a contractual link of several costs carriers, for example for green and underground infrastructure.

Quality of life: A reliable supply and disposal with simultaneously green and attractive cityscape offers good prerequisites for high quality of life. Planning freedom of action is therefore sought after also under congested space conditions. These are convenient for example if in the upper pipeline trench area – where roots mostly already penetrate today - vegetation layers are planned, on which construction is possible. Simultaneously, the direct surrounding of the underground infrastructure is then to be protected by root-repelling filling zones so that root damages to the pipelines are diminished.

Sustainability: A sustainable development of the cities requires methodical approach. This relates also to the underground with its manifold utilization. The present competition about underground space, for example expressed by the demand for minimum distances or barrier zones, massively limits the adaptability. Climate variations and demographic developments however demand flexibility and early identification and planning of action options. Here, multifunctional utilisations of bedding and filling materials for nearly complete coverage of pipeline trenches should gain importance.

Authors:
Dr.-Ing. Bert Bosseler,
Research Director
Dipl.-Ing. Christoph Bennerscheidt
Dipl.-Ing. Martin Liebscher
IKT - Institute for Underground infrastructure

Prof. Dr. Thomas Stützel,
Ruhr University Bochum

References

[1] Geiger, W.; Dreiseitl, H.: Neue Wege für das Regenwasser – Handbuch zum Rückhalt und zur Versickerung von Regenwasser in Baugebieten: 2. Aufl. 2001 R. Oldenbourg Verlag GmbH.

[2] Embrén, B.; Bennerscheidt, C.; Stål, Ö.; Schröder, K.: Optimierung von Baumstandorten. wwt wasserwirtschaft wassertechnik, 07-08/2008.

[3] Schröder, K.: Stadtbäume und technische Infrastruktur – Konkurrenz unter Tage. Grünforum, 2005, Band 35, Heft 4, S. 34-38.

[4] Wiersum, L.K.: The relationship of the size and structural rigidity of pores to their penetration by roots, Plant and Soil IX, S. 75-85, 1957.

[5] Bohne, H.; Hartge, K.H.: Auswirkungen der Gefügegeometrie auf den Wuchs von Getreidekeimlingen, Mitt. Dt. Bodenk. Ges. 34: S. 141-144, 1982.

[6] Balder, H.: Die Wurzeln der Stadtbäume, Parey-Verlag, 1998; zitiert in [10].

[7] Scheffer, F.; Schachtschabel, P.: Lehrbuch der Bodenkunde, 14. Aufl., Enke-Verlag, 1998; zitiert in [10].

[8] Schönfeld, P.: Baumpflanzungen in der Stadt: Einsatz von Baumsubstraten und Bauweisen nach FLL und ZTV-Vegra-Mü. FLL-Fachtagung Optimale Standorte sichern Stadtbäumen langes Leben! Standortvorbereitung und Standortsanierung, Erfurt, 05/2009.

[9] FLL – Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.: Empfehlungen für Baumpflanzungen, Teil 2: Standortvorbereitungen für Neupflanzungen; Pflanzgruben und Wurzelraumerweiterung, Bauweisen und Substrate. FLL, Bonn, 2004.

[10] Stützel, Th.; Bosseler, B.; Bennerscheidt, C.; Schmiedener, H.: Wurzeleinwuchs in Abwasserleitungen- und -kanäle - Ursachen, Prüfung und Vermeidung. Endbericht zum Forschungsvorhaben, gefördert durch das MUNLV NRW, Lehrstuhl für Spezielle Botanik der Ruhr-Universität Bochum und IKT – Institut für Unterirdische Infrastruktur, August 2004.

[11] Stützel, Th.; Bosseler, B.; Bennerscheidt, C.; Schmiedener, H.; Streckenbach, M.: Wurzeleinwuchs in Abwasserleitungen und Kanäle - Ergänzungsvorhaben. Endbericht zum Forschungsvorhaben, gefördert durch das MUNLV NRW, Ruhr-Universität Bochum, Lehrstuhl für Spezielle Botanik und Botanischer Garten und IKT - Institut für Unterirdische Infrastruktur, Bochum Gelsenkirchen, 06/2007.

[12] DIN 18920: Vegetationstechnik im Landschaftsbau – Schutz von Bäumen, Pflanzenbeständen und Vegetationsflächen bei Baumaßnahmen. Beuth Verlag, Berlin, 09/1990.

[13] FGSV – Forschungsgesellschaft für Straßen- und Verkehrswesen, Arbeitsgruppe Straßenentwurf: RAS-LP 4 Richtlinien für die Anlage von Straßen, Teil Landschaftspflege, Abschnitt 4: Schutz von Bäumen, Vegetationsbeständen und Tieren bei Baumaßnahmen. FGSV, 1999.

[14] ATV-DVWK-A 127: Statische Berechnung von Abwasserkanälen und -leitungen. Regelwerk der DWA Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V., 3. Auflage, 08/2000.

[15] Janssen, H.A.: Versuche über Getreidedruck in Silozellen. Zeitschrift des Vereins deutscher Ingenieure, Band XXXIX, Nr. 35, S. 1045-1049, 1895.

[16] Terzaghi, K.: Stress distribution in dry sand and in saturated sand above a yielding trap door. First International Conference of Soil Mechanics and Foundation Engineering, Cambridge, 1936.

[17] Marston, A.: Iowa Engineering Experiment Station. Bull. no. 96, 1930.

[18] El Shahid, S.: Zur Belastung erdverlegter Rohrleitungen nach dem Ziehen von Verbauprofilen. Dissertation, Ruhr-Universität Bochum, Technisch-wissenschaftliche Berichte des IKT - Institut für Kanalisationstechnik, Bericht 97/5, Gelsenkirchen, 1997.

[19] Leonhardt, G.: Einige Bemerkungen zum statischen und bodenmechanischen Konzept des ATV-Arbeitsblattes A 127. KA Korrespondenz Abwasser, 06/1984.

[20] Hornung, K.; Kittel, D.: Statik erdüberdeckter Rohre/Structural analysis of buried pipes. Bauverlag, Wiesbaden Berlin, 1989.

[21] Moser, A.P., Folkman, S.: Buried pipe design. Third edition, McGraw-Hill, 2008.

[22] Leonhardt, G.: Einfluss der Bettungssteifigkeit auf die Tragfähigkeit und die Verformungen von flexiblen Rohren. Strasse Brücke Tunnel, 03/1972.

[23] DWA-A 139: Einbau und Prüfung von Abwasserleitungen und -kanälen (Entwurf). Regelwerk der DWA Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall, 05/2008.

[24] DIN EN 1610: Verlegung und Prüfung von Abwasserleitungen und -kanälen. Beuth Verlag, Berlin, 10/1997.

[25] Triantafyllidis, T.; Bosseler, B.; Asic, I.; Liebscher, M.: Ausführungsrisiken beim Einsatz von Bettungs- und Verfüllmaterialien im Rohrleitungsbau. Endbericht zum Forschungsvorhaben, gefördert durch das MUNLV NRW, Ruhr-Universität Bochum, Lehrstuhl für Grundbau und Bodenmechanik und IKT - Institut für Unterirdische Infrastruktur, Bochum Gelsenkirchen, 2006.

[26] IKT: Fließfähige Bettungsmittel – Gut gebettet liegt länger. IKT-Ergebnisse 2007, Heft 1.

[27] IKT: EPS-Bettungskissen in der offenen Bauweise. Endbericht zum Forschungsvorhaben, gefördert durch das MUNLV NRW, IKT - Institut für Unterirdische Infrastruktur, Gelsenkirchen, 08/2007.

[28] Röper, W.: Flüssigboden und Kunststoffrohr – Der Einsatz von EPS-Bettungskissen im Kanalbau – Erfahrungen verschiedener Baustellen. IB Röper, Melle, 2009.

Heat from waste-water

Figure 1: Supply and return lines to the heat-exchanger

The recovery of heat from waste-water is a topic that features energy and waste-water economic dimensions at the same time and can thus entail also a profitable field of activity for network operators. In the past, the IKT examined how the use of heat exchangers in the channel can be technical and economically feasible. The IKT offers possibilities for the collaboration with network operators.

Mode of operation of heat recovery from waste-water

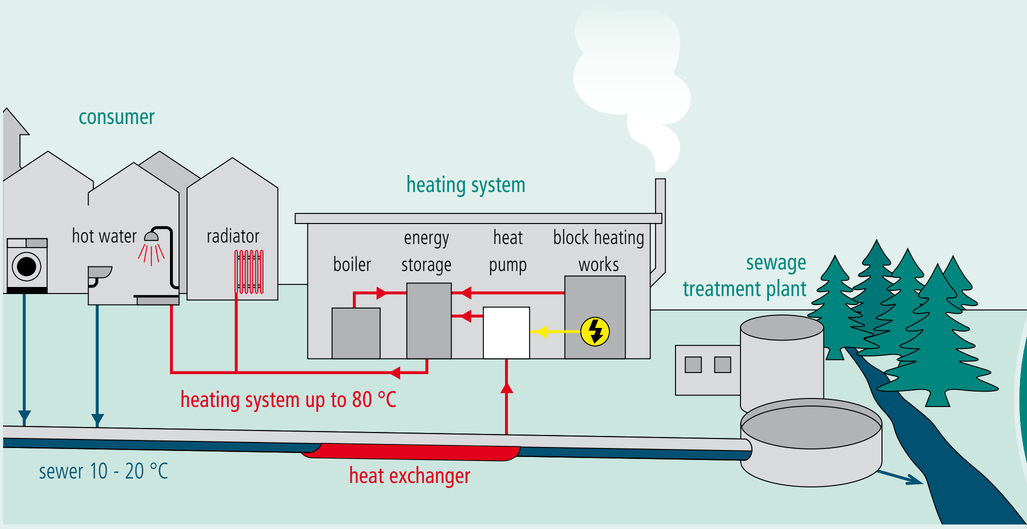
Many uses of drinking water are connected with a heating process, so that waste-water is associated with steady heat dissipation into the sewer system. Depending on the season, waste-water generally features a temperature level between 10 and 20°C. This heat energy can be recovered by means of waste-water heat recovery systems (WHRSs) and can be used for heating real estate as well as for hot water supply. Components of a WHRS are heat exchangers, transmission lines and a heat pump.

The recovery of heat from waste-water takes place in three heat exchange processes: In the heat exchangers above which the waste-water flows, a medium circulates thereby adapting to the temperature of waste-water. The heated medium is fed to a heat pump through transmission lines. There, a second heat exchange takes place through a medium inside the heat pump. This evaporates as result of the heat supply from the channel. In the heat pump, compression of the evaporated medium occurs now by means of which the temperature is raised to a useful level. In a third heat exchange, the heat is fed into the heating circuit.

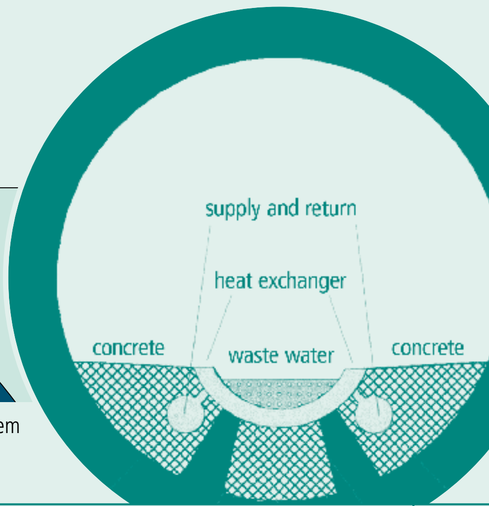
A peculiarity of the heat recovery from waste-water exists in that this is component of a hybrid heating system: The heat pump supplies the base load demand; a conventional boiler is used additionally for peak load demand. A further peculiarity lies in the possibility of using WHRSs for the air-conditioning of rooms. In that case, the heat exchange operates in the reverse direction, i.e. surplus room heat is transferred to waste-water.

Influence of heat exchangers on the sewer system

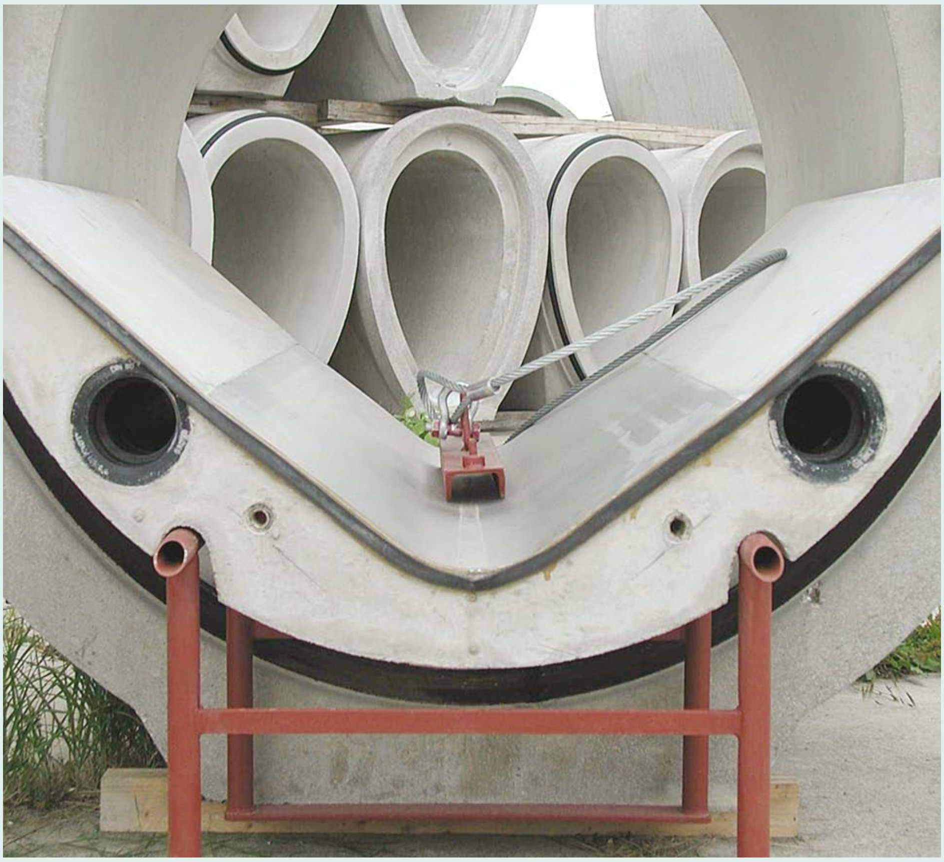
The IKT examined the „Heat recovery from sewer systems" within the scope of the research project, the influence of heat exchangers on the sewer system with respect to working safety, durability, and effect of sewer cleaning. In that case, the IKT researchers oriented themselves towards the heat exchangers, system Rabtherm® installed in Leverkusen/Germany. These heat exchangers consisting of non-rusting stainless steel, with the Material Number 1.4571, are incorporated in a dry-weather sewer and have direct contact with waste-water.



Mode of operation of a waste-water heat recovery system



Right: Heat exchanger in the sewer system



Heat exchanger elements Rabtherm® in a sewer (Figure: Wallstein Ingenieur GmbH)

The investigations yielded that negative effects on leakage tightness or durability are hardly expected just as can restrictions of durability through corrosion be expected. Also sewer cleanings allow no changes to be expected, which have a negative influence on the durability of heat exchanger elements.

With respect to working safety, it could determined to a safe extent that the usual caution necessary, for example, when inspecting brick-built sewers is also appropriate and sufficient when inspecting stainless steel heat exchangers.

Recovery of heat from waste-water

The IKT has worked out the conditions for reasonable use of WHRSs and compiled them in a requirement catalogue. It has become evident that for reasonable utilization of waste-water heat, notable technical and economic restrictions must be observed.

The technical requirements are in the first place directed to features of the sewer system. For the heat recovery from waste-water, there are suitable sewer system sections if the following criteria are fulfilled:

- Minimum cross-section> ND 800 (accessible channel)
- Middle dry-weather drainage> 12 to 15 l/s
- Minimum gradient
- Material and condition of the channel
- no restrictions of the required hydraulic reserves
- sewers that are as straight as possible, with a length of up to 200 m
- Accessibility for building phase and operation
- Exclusion of falling short of the minimum operating temperature for waste-water treatment systems

Altogether, the technical requirements are already manifold. Based on the size of the sewer system networks, sewer system sections can be found, which fulfil technical restrictions and are thus fundamentally available for the heat recovery from waste-water.

Marketing of heat from waste-water

Beyond the recovery, the marketing of the heat energy plays a central role. Therefore, also economic restrictions for the use of WHRSs are to be observed. Suitable locations for the marketing of heat from WHRSs are characterised in that

- in maximum distance of 200 m from the place of heat recovery a heat consumption demand of minimum 150 kW can be served,
- the WHRS is possibly continuously used at full capacity (sale of heat energy in winter and air-conditioning energy in summer) and
- the timeline for investments in new channel construction or restoration, energy supply and heating system coincide.

If these prerequisites are fulfilled, the economic advantages of an WHRS can come to effect. However, a further step is required up to the realisation of a WHRS: The involved participants must undergo a voluntary and durable cooperative relationship. Involved participants are channel network operators and energy providers on the supply side and real estate owners on the demand side. In this constellation, cooperation can come into being if all expense (investment and overhead) can be covered and furthermore a profit can be collect from the yields of marketing the heat energy. In that case, the heat energy must be offered at competitive prices so that heat from waste-water also becomes interesting for the demand side.

The profitability is the economic key criterion in the marketing of waste-water heat. A profitable WHRS exists if heat energy is offered at competitive prices and from the proceeds all occurring investment and overhead as well as the profit claims of the supplier (channel network operator, energy provider) are served.

Potential of heat recovery from waste-water in NRW

With the help of heat exchangers, 1.5 kWh per Kelvin temperature difference can be recovered from 1,000 litres of waste-water. The output capacity per metre of heat exchanger is about 2.5 kW. Thus, a system with a maximum of 200 m long heat exchanger features output capacity of approximately 500 kW.

Whilst considering technical and economic restrictions, the IKT has the roughly calculated the potential for the recovery and marketing of heat from waste-water for the State of NRW. According to the IKT's estimation by considering the criteria cited above, an annual potential exists for about 50 WHRSs with an entire output capacity of 25 megawatts within the approximately 87,000 km of long sewer system in NRW (German state North Rhine Westphalia).

Altogether only a niche potential for heat recovery from waste-water exists today, which will not be exhausted for along. In that case, some aspects are to be emphasized especially supplementarily: Because the potential of 50 WHRS involves an annual value, the energy economic and environmental effects (reduction of primary energy use and CO_2 emission) would cumulate over the time axis.

Moreover, an increased competitiveness of WHRS is to be expected with the increase of crude oil prices because in WHRSs primary energy is required only to comparatively small scope. In the end, also learning effects can find positive expression in the economics during erection and operation of WHRSs.

Systematic development of waste-water as heat source

In order to be able to use heat from waste-water, first of all a careful selection of suitable locations must occur based on the criteria illustrated above. For the selected locations, the profitability to be expected must be determined based on economic calculations in an individual case. In case of a positive result, the basic prerequisites are fulfilled for the cooperation of involved participants.

The development of the waste-water heat source according to the opinion of the IKT are contrary to a combination of lack of information and different knowledge distribution (information asymmetries): Suitable locations are fundamentally available, however, they are known to neither the channel network operators nor to the energy providers. Moreover, information asymmetries exist indicating that energy providers know little about the waste-water and energy quantities at disposal in the sewer system. Also, it is not well known to the energy providers when channel sections are restored and where the channel sections are, which generally fulfil the technical prerequisites for the heat recovery from waste-water. A comparison with the demand for heat energy can therefore not take place. On the side of the network operators, the knowledge about suitable sewer system sections is available, on the other hand not the knowledge about the chances and risks of marketing of energy.

If now the waste-water heat source is supposed to be developed systematically, then the information asymmetries must be dismantled. This can occur in the following idealised steps:

- The network operators disclose those locations for which the technical requirements are fulfilled for the heat recovery from waste-water.
- The energy providers undertake an assessment of the locations with regard to the marketing chances.
- For potentially suitable locations, an economic viability calculation is performed.
- Sewer network operators and energy providers agree on a binding regulation about the distribution of the profit as well as of the tasks and obligations for the erection and operation of the WHRSs.

Benefit for sewer network operators

The recovery of heat from waste-water can be advantageous for sewer network operators because revenue is earned from the provision of the sewer system for the heat recovery. In that case, at minimum, the costs incurred by the utilization the waste-water heat must be compensated including the additional overheads (for example, increased inspection and cleaning expenses). In order to give network operators an incentive for commitment to the heat recovery from waste-water, they must additionally participate in the profits from marketed waste-water heat. As far as the financial freedom of action for mastering of the draining task can be improved in this manner, indirect benefit also emerges for to the benefit of the water conservation.

A further interesting aspect exists, in that, the sewer system gains importance for energy supply system, not often perceived by the public, beyond the function of the waste-water disposal. Energy economic topics enjoy much attention in the public, above all if environmentally friendly energy sources play a role. If the services around the sewer system come into the consciousness of citizens more strongly through the heat recovery from waste-water, then advertisements for positive attitude to the activities by channel network operators can be made in this manner. Good relations between channel network operators and citizens can pay off at some point in time if channel network operators must approach the citizens with less popular tasks, for example, with regard to the drainage of real estate.

Heat exchanger elements Rabtherm®
(Figure: Wallstein Ingenieur GmbH)

Rabtherm® heat-exchanger elements not yet installed
(Figure: Wallstein Ingenieur GmbH)

What the IKT can do for you

The IKT has the know-how for the identification of sewer system sections suitable for the heat recovery from waste-water. With the application of this knowledge, from neutral and independent side, to the existing sewer system of your community, the cornerstone can be laid for a systematic development of waste-water heat source. The IKT offers following services:

Feasibility study

- Report on the conditions and possibilities of heat recovery in your community
- Process design for further development of waste-water heat source
- Designation of the participants to be involved

Potential analysis

- detailed investigation to identify potentially suitable locations
- energy and environmental potential of the heat recovery from waste-water

Contact development and presentation

- Dialogue with the participants to be involved at municipal level
- Development of networks at superregional level
- Experience exchange
- Standardisation of procedures

Your advantages: High economic viability, decision certainty, image effects

Point of contact in the IKT

If you would like to know, which potential your sewer system network offers to the heat recovery from waste-water, please get in touch with. We will be grateful to discuss with you in a personal meeting about the possibilities of support by the IKT.

Dr. rer. oec. Lutz Rometsch
Phone: +49(0)209 17806-12
rometsch@ikt.de

Dipl.-Ing. Christoph Bennerscheidt
Phone: +49(0)209 17806-25
bennerscheidt@ikt.de

Why IKT product test?

The objective of IKT product tests is to provide network operators with reliable and independent information on the strength and weaknesses of products and methods of waste water technology. The IKT product tests are done together with network operators who follow the whole tests in several meetings. A central aspect of IKT product tests is the practical product test, e.g. under construction or operating conditions.

The focus of the examinations is not the compliance with individual standards or bodies of rules and regulations, but the reliable fulfilment of network operator requirements during construction and operation. The service life under expected conditions such as load, groundwater, earth pressure, volume of traffic or high-pressure cleaning, is the focus of attention. As a result the network operators are provided with independent, practice-related, and technically well-founded information concerning the strengths and weaknesses as well as areas of application and limits of the tested products. The network operators are quickly and comprehensively informed on product quality with an understandable evaluation scheme and a test seal. At the end of an IKT product test the tested products and methods are all assessed with marks from VERY GOOD to POOR.

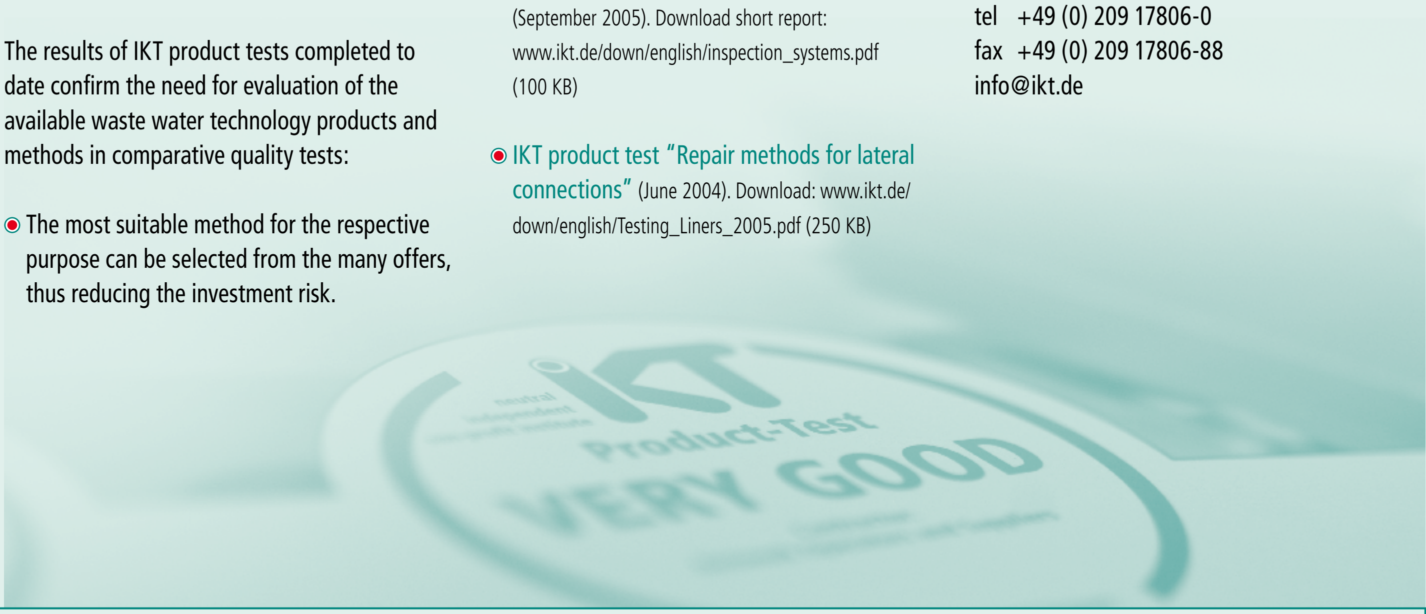
The results of IKT product tests completed to date confirm the need for evaluation of the available waste water technology products and methods in comparative quality tests:

- The most suitable method for the respective purpose can be selected from the many offers, thus reducing the investment risk.
- The requirements of the network operators are the basis for the development of products and methods, as improvement potentials of products and methods are identified and documented in the tests.
- IKT product tests can result in a "Closed loop of product improvement", which will lead to innovations and an improved market situation.

Completed IKT product tests:

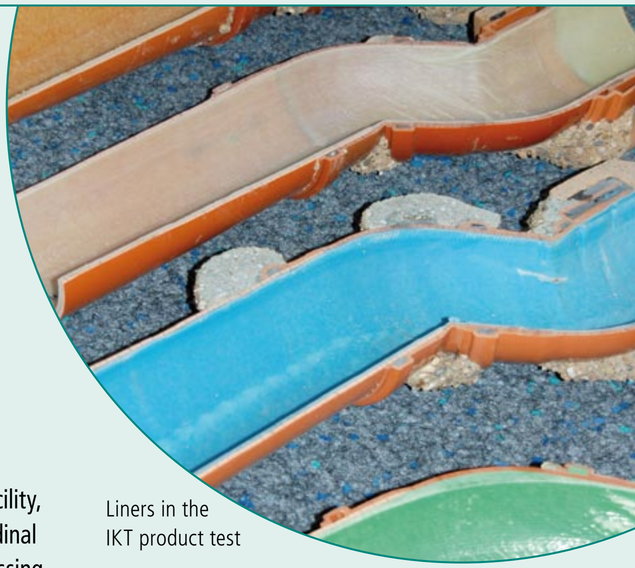
- IKT product test "Odour filters"
  (April 2010)
- IKT product test "Tube liners for lateral pipes 2010"
  (March 2010)
- IKT product test "Repairing methods for main pipes"
  (July 2009)
- IKT product test "Tube liners for lateral pipes"
  (November 2005) Download: www.ikt.de/down/f0116kurzbericht_liner_en.pdf (870 KB)
- IKT product test "Inspection systems for domestic sewer networks"
  (September 2005). Download short report: www.ikt.de/down/english/inspection_systems.pdf (100 KB)
- IKT product test "Repair methods for lateral connections" (June 2004). Download: www.ikt.de/down/english/Testing_Liners_2005.pdf (250 KB)
- IKT product tests of new or further developed top hat liners and robotic systems from different producers following the test procedure of the IKT product test "Repair methods for lateral connections"
  (November 2004 to February 2006)
- IKT product test "Lateral connections"
  (June 2002)
- IKT product tests of new or further developed saddles from different producers following the test procedure of the IKT-Product-Test "Lateral connections"
  (December 2002 to June 2010)

contact IKT
tel +49 (0) 209 17806-0
fax +49 (0) 209 17806-88
info@ikt.de



Competition moves up to the test winner

Reprint of IKT product test „tube liners for lateral pipes“



Liners in the IKT product test

The contestants are close on the heels of the test winner of 2005. In the first IKT product test of house connection liner five years ago, a clearer advantage of the test winner BRAWOLINER appeared in the competition. The latter did not only watch but rather has considerably improved its products in the meantime. Now (almost) all lie WELL at the same level. Only one needs to catch up somewhat, is a prototype however.

Liner in the test

A steering committee consisting of 17 municipal representatives accompanied the product test over the entire project duration. It also made the decision for the liner selection, among others. Only bend-capable liner products were used.

Test installation

In test lines in the IKT large scale test facility, typical damage patterns such as longitudinal and transverse cracks, fragments and missing pipe pieces were reproduced. Two damage scenarios were constructed (cf. Tab. 2):

- Standard situation: Minimum requirements for bend-capable liners
- Extreme situation: Increased requirements through material and nominal width change

Evaluation criteria

The system tests in the test lines (weighting 80%) as well as the quality assurance of the procedure supplier (weighting 20%) were evaluated. Evaluation criteria of the system test were functionality, water tightness, load-bearing capacity as well as the sensitivity to buoyancy.

Test results of standard situation

In the standard situation, four out of five liners show GOOD performances: BRAWOLINER XT, LineTEC ProFlex Liner, DrainLiner and RS MaxLiner FLEX S. Among the system tests weighted with 80%, all four show an equally high level (GOOD). In the quality assurance (20% weighting), they achieve VERY GOOD rating.

Test lines, extreme situation before covering: different pipe materials and diameter in the IKT large-scale test facility

Tab. 1: Liners in the IKT product test house connection liner 2010

Manufacturer	Liner
Karl Otto Braun GmbH & CO. KG	BRAWOLINER XT
RS-Technik AG	RS MaxLiner-FLEX S
Trelleborg Pipe Seals Duisburg GmbH	DrainLiner
	DrainPlusLiner
	epros®DrainGlassLiner (Prototyp)
	epros®DrainPlusGlassLiner (Prototyp)
Vereinigte Filzfabriken AG	lineTEC ProFlex Liner

Tab. 2: Test installation in the IKT large-scale test facility

Standard situation (= Minimum requirement for liners)	Extreme situation (= Maximum requirement on liner)
Vitrified clay ND 150	Vitrified clay ND 125 and ND 150
Material and nominal widths are uniform	PVC ND 125
no change in dimension	Dimension change ND 125 to ND 150
no material change	Material change PVC to vitrified clay
8 Bends	12 Bends
21 Damages	22 Damages
Rehabilitation through revision opening	Rehabilitation through 90°-bends

The epros®DrainGlassLiner that entered into the race as prototype falls compared to the group of four and comes altogether to the overall grade ADEQUATE. Although it is bonded clearly stronger than the competitors with the old pipe, which however leads to significantly higher fracture risks under buoyancy load by ground water. Moreover, as a prototype it still lacks technical approval by the Deutsches Institut für Bautechnik (German Institute for Construction Technology, a government body, German abbreviation: DIBT) and environmental impact certificates.

Test results, extreme situation

In the much more demanding extreme situation, the BRAWOLINER XT qualifies best (VERY GOOD) and thus remains at the same achievement level as in the previous product test of 2005.

The other four liners follow it: DrainPlusLiner, lineTEC ProFlex Liner, RS MaxLiner FLEX S and the prototype epros®DrainPlusGlassLiner. In system test (80% weight), they are all GOOD. Only in quality assurance (20% weight), does the prototype fall because it lacks DIBt approval and UVP certification. Therefore, it attains a strong SATISFACTORY while the remaining three finished with GOOD.

Clear improvement in functionality

Even in bends and offsets, the products hardly showed considerable fold formation. Here there were clear visible improvements compared to earlier test results. Clogging dangers are hardly expected or not at all.

All liners are tight in strand test

In the air pressure test according to DIN EN 1610 all liners proved to be water tight. Even after simulated operation loads by 5-fold high-pressure cleaning and isolated chain spinning, the tested liners remained watertight. Therefore, they fulfil the legal and normative tightness requirements as far as they are correctly incorporated.

Weakness laminate

The characteristics guaranteed in the DIBt approval of the laminates with respect to tightness and minimum wall thickness were not fulfilled a multiple times. More than one-fifth of the laminate test spots did not pass the water tightness test according to APS because the laminate was permeable to water.

Nevertheless, the liners were altogether watertight in the strand test. Apparently, the installation foil and/or adhesion to the old pipe assume the sealing function.

Resin leakage at damaged points

Especially at extensively damaged spots and leaky sockets, considerable quantities of liner resin leaked apparently uncontrolled into the ground. A thinner wall thickness is to be reckoned with at these points. Tightness and load-bearing capacity were characterised by the composite behaviour between liner material, resin leakage as well as old pipe and ground.

Resin leakage at damaged area

Buoyancy risks due to ground water rise

Some liners feature a goal conflict: In order to avoid seepage, they must be bonded strongly with the old pipe. A good adhesion entails, however, an increased fracture risk, namely then, when it comes to the buoyancy through ground water.

Infiltration measurements showed that the cracks in liner material can again lead to extreme infiltration quantities under outside water pressure where appropriate resulting in negligible hence in the liner material that question the rehabilitation goal - infiltration tightness.

High demands on execution

In the installation for the product test, it appeared that the execution on site required technical understanding and skill. This concerns above all the rehabilitation preparations such as cleaning and milling machine tasks as well as soaking on the spot.

Quality supervision necessary on the spot

The test results show that relevant quality characteristics could be examined in the test in detail, however are hardly understood on the spot. This applies especially to the recognition of later weaknesses under outside water pressure, verification of laminate tightness as well as measurement of wall thickness distribution over the pipe strand surface.

Conclusion

In the entire view, the IKT product test „tube liners for lateral pipes" shows that the rehabilitation of defective house connection lines with the tube lining procedure also functions in difficult line routing. This applies to the seal against exfiltration. The tested liner systems are GOOD throughout.

Somewhat different in approach is the situation with infiltration rehabilitation. Buoyancy risks caused by rising ground water occur in this case as consequence of the extensive line sealing. The buoyancy risks can lead to pipe movements and this to liner fractures. So that this does not happen, an integrated rehabilitation planning is called for, which considers the ground water level.

Results available on the Internet

The article represents the results of the IKT product test only in excerpts. The complete research report is on the Internet ready for download: www.ikt.de

Author

Dipl.-Ing. (FH) Kathrin Harting
IKT - Institute for Underground Infrastructure

(Result tables on the following pages)

Table 3: IKT product test „tube liners for lateral pipes“

Standard situation[1]:

Rehabilitation of three connection sewage lines made of vitrified clay ND 150; correct connection with a connection pipe above the abutment of the main pipe; inversion with PVC KG revision openings at the beginning of the vitrified clay sewage line; bends: 45° and 30°; introduced damages: longitudinal cracks, transverse cracks, fragment formation, missing pipe pieces, improperly fabricated inlet, leaky pipe connections, fat deposits.

Liner supplier			Karl Otto Braun GmbH & CO. KG	VFG Vereinigte Filzfabriken AG	RS-Technik AG	Trelleborg Pipe Seals Duisburg GmbH	Trelleborg Pipe Seals Duisburg GmbH
Tube liner			BRAWOLINER XT 	lineTEC ProFlex Liner 	RS MaxLiner-FLEX S 	DrainLiner 	epros®DrainGlassLiner (Prototype) 
Used substrate material			Polyester fibre tube with polyester urethane film	Polyester fibre tube with polyurethane film	Polyester fibre tube with polyurethane film	Polyester needle felt tube with polyvinylchloride film	Polyester needle felt tube/ECR glass with Polyurethane film
Used resin system			BRAWO I	Biresin lineTEC EP 40	MaxPox 15-40	EPROPOX VIS A2 / B2	EPROPOX VIS A4 / B4
IKT - Test assessment: Standard situation*			**good (1.6)**	**good (1.8)**	**good (1.9)**	**good (2.1)**	**adequate (3.7)**
System test (weighting 80%)			**good (1.8)**	**good (2.1)**	**good (2.1)**	**good (2.4)**	**satisfactory (3.3)**
Functional capability[2] (20%)			1.6	2.1	1.9	1.9	2.3
Tightness (60%)			1.6	1.8	1.8	1,8	1.8
Tightness (60%)	Pipeline test (40%)	After rehabilitation (30%)	1.0	1.0	1.0	1.0	1.0
		After HP cleaning (10%)	1.0	1.0	1.0	1.0	1.0
	Laminate test (10%)	APS-test[3] (10%)	4.4	6.0	6.0	6.0	6.0
	Outside water pressure (10%)	Seepage (2%)	1.0	1.0	1.0	1.0[9]	1.0[9]
		Peeling of interior film (4%)	1.0	1.0	1.0	1.0	1.0
		Bulging (4%)	1.0	1.0	1.0	1.0	1.0
Load-bearing capacity of structure (20%)			2.6	2.6	3.1	4.6	3.5
Load-bearing capacity of structure (20%)		Combine thickness[4] (6%)	3.0	3.0	3.0	3.0	6.0
		E-Modulus[5] (6%)	4.4	1.0	1.0	6.0	1.0
		24h-Creep tendency[6] (6%)	1.0	4.4	6.0	6.0	4.4
		Tightness[7] (2%)	1.0	1.0	1.0	1.0	1.0
Sensitivity under buoyancy[8]			Risk observed	Risk observed	Risk conceivable	Risk conceivable	Risk to expect (depreciation[10])
Quality assurance (weighting 20%)			**very good (1.0)**	**very good (1.0)**	**very good (1.0)**	**very good (1.0)**	**poor (5.5)**
DIBt-certification[11] (50%)			yes	yes	yes	yes	no
environmental impact certificates of the resin presented[11] (10%)			yes	yes	yes	yes	no
Process handbook and training[11] (20%)			yes	yes	yes	yes	no
External monitoring[11] (10%)			yes	yes	yes	yes	no
Proof of disposal suitability[11] (10%)			yes	yes	yes	yes	yes
Construction sites investigation			practice friendly installation	practice friendly installation	practice friendly installation	practice friendly installation	practice friendly installation
Additional information: Available for			ND 100 to ND 200	ND 100 to ND 200	ND 100 to ND 200	ND 100 to ND 300	ND 100 to ND 400
Pipeline test after mechanical cleaning			tight	tight	tight	tight	tight
Recommended improvements			Solving target conflict between adhesion and offset possibility under buoyancy. Strong adhesion led in two test stretches to buoyancy damages.	Solving target conflict between adhesion and offset possibility under buoyancy. Strong adhesion led in two test stretches to buoyancy damages.	Solving target conflict between adhesion and offset possibility under buoyancy. Strong adhesion could lead to buoyancy damages.	Solving target conflict between adhesion and offset possibility under buoyancy. Strong adhesion could lead to buoyancy damages.	Solving target conflict between adhesion and offset suitability under buoyancy. Strong adhesion led in all test stretches to buoyancy damages.

1 The designation „Standard situation" refers to the geometry of the connection sewage.
2 Assessment of the functionality through optical assessment of the rehabilitated standard situation through network operators: 100 Points = 1.0 to 0 points = 6.0; computation by means of a non-linear function.
3 Assessment: 100% Passed tightness tests according to APS guideline = 1.0; a test series according APS guideline leaky = 4.4; from 2 test series according APS guideline leaky = 6.0.
4 Assessment: Demanded combine thickness kept = 1.0; composite thickness is not attained at individual points, but reaches the means, the demanded value = 3.0; demanded composite thickness predominantly not reached = 6.0.
5 Assessment: Demanded E-modulus in accordance with DIBt certification observed in 3 tests = 1.0; observed in 2 tests = 4.4; observed in only one or no tests observed = 6.0.
6 Assessment: Permissible 24-hr E-modulus in accordance with DIBt certification observed in 3 tests = 1.0; observed in 2 tests = 4.4; observed in only one or in no tests observed = 6.0.
7 Assessment: Demanded tightness in accordance with DIBt certification observed in 3 tests = 1.0; observed in 2 tests = 4.4; observed in only one or no tests observed = 6.0.
8 Assessment: Buoyancy damages did not occur in the test = risk conceivable, buoyancy damages occurred in the test = risk observed; buoyancy damages occurred in the test = risk to expect.
9 Attachment from the house connection line to the main sewage with an LCR brim, made of optical fibre reinforced polypropylene with silicate resin system type W (winter resin) under the use of a pipe rehabilitation device (LCR packer).
10 Depreciation of partial result „System test" by one grade (from 2.3 auf 3.3) because in every test stretches at least a Mal damages were observed under drive load.
11 Assessment: Available = yes; not available = no; allowances/testimonies/proofs must apply to the materials used in the test.
* Grade calculation based on unrounded value

Assessment key of test results: Very gut = 1.0 - 1.5 good = 1.6 - 2.5 satisfactory = 2.6 - 3.5 adequate = 3.6 - 4.5 inadequate = 4.6 - 5.5. poor = 5.6 - 6.0.

IKT product test

Table 4: IKT product test „tube liners for lateral pipes"

Extreme situation[1]:

Rehabilitation of three connection sewages made of vitrified clay and PVC-KG of nominal width ND 125 and ND 150; correct connection with a connection pipe in the abutment of the main tube; inversion through a vitrifed clay bend 90° ND 125 at the beginning of the stone sewage; bends: 45°, 30° and 15°; introduced damages: longitudinal cracks, transverse crack, fragment formation, missing pipe pieces, improperly fabricated material change vitrified clay on PVC KG, improperly fabricated nominal change ND 125 on ND 150, leaky pipe connections, fat deposits.

Liner supplier			Karl Otto Braun GmbH & CO. KG	Trelleborg Pipe Seals Duisburg GmbH	VFG Vereinigte Filzfabriken AG	RS-Technik AG	Trelleborg Pipe Seals Duisburg GmbH
Tube liner			BRAWOLINER XT  Polyester fibre tube with polyester urethane film	DrainPlusLiner  Polyester needle felt tube with polyurethane film	lineTEC ProFlex Liner  Polyester fibre tube with polyurethane film	RS MaxLiner-FLEX S  Polyester fibre tube with polyurethane film	epros®DrainPlusGlassLiner (prototype)  Polyester needle felt tube with polyurethane film
Used resin system			BRAWO I	EPROPOX VIS A2 / B2	Biresin lineTEC EP 40	MaxPox 15-40	EPROPOX VIS A4 / B4
IKT - Test assessment: Extreme situation*			**very good (1.3)**	**good (1.8)**	**good (1.9)**	**good (1.9)**	**satisfactory (2.9)**
System test (weighting 80%)			**very good (1.3)**	**good (2.0)**	**good (2.1)**	**good (2.1)**	**good (2.3)**
Functional capability[2] (20%)			2.1	2.6	2.2	2.5	2.4
Tightness (60%)			1.0	1.0	1.8	1.8	1.8
Tightness (60%)	Pipeline test (40%)	After rehabilitation (30%)	1.0	1.0	1.0	1.0	1,0
		After HP cleaning (10%)	1.0	1.0	1.0	1.0	1,0
	Laminate test (10%)	APS-test[3] (10%)	1.0	1.0	6.0	6.0	6,0
		Seepage (2%)	1.0	1.0[9]	1.0	1.0	1,0[9]
	Outside water pressure (10%)	Peeling of interior film (4%)	1.0	1.0	1.0	1.0	1,0
		Bulging (4%)	1.0	1.0	1.0	1.0	1,0
Load-bearing capacity of structure (20%)			1.6	4.6	2.6	2.6	3.5
Load-bearing capacity of structure (20%)		combine thickness[4] (6%)	3.0	3.0	3.0	3.0	6.0
		E-Modulus[5] (6%)	1.0	6.0	4.4	1.0	1.0
		24h-Creep tendency[6] (6%)	1.0	6.0	1.0	4.4	4.4
		Tightness[7] (2%)	1.0	1.0	1.0	1.0	1.0
Sensitivity under buoyancy[8]			Risk conceivable	Risk observed	Risk conceivable	Risk conceivable	Risk observed
Quality assurance (weighting 20%)			**very good (1.0)**	**very good (1.0)**	**very good (1.0)**	**very good (1.0)**	**poor (5.5)**
DIBt-certification[10] (50%)			yes	yes	yes	yes	no
environmental impact certificates of the resin presented[10] (10%)			yes	yes	yes	yes	no
Process handbook and training [10] (20%)			yes	yes	yes	yes	no
External monitoring[10] (10%)			yes	yes	yes	yes	no
Proof of disposal suitability[10] (10%)			yes	yes	yes	yes	yes
Construction sites investigation			practice friendly installation	practice friendly installation	practice friendly installation	practice friendly installation	practice friendly installation
Additional information: Available for			ND 100 to ND 200	ND 100 to ND 300	ND 100 to ND 200	ND 100 to ND 200	ND 100 to ND 400
Pipeline test after mechanical cleaning			tight	tight	tight	tight	tight
Recommended improvements			Solving target conflict between adhesion and offset suitability under buoyancy. Strong adhesion could lead to buoyancy damages.	Solving target conflict between adhesion and offset suitability under buoyancy. Strong adhesion led in a test stretch to buoyancy damages.	Solving target conflict between adhesion and offset suitability under buoyancy. Strong adhesion could lead to buoyancy damages.	Solving target conflict between adhesion and offset suitability under buoyancy. Strong adhesion could lead to buoyancy damages.	Solving target conflict between adhesion and offset suitability under buoyancy. Strong adhesion led in two test stretches to buoyancy damages.

1 The designation „Extreme situation" refers to the geometry of the connection sewage.
2 Assessment of the functionality through optical evaluation of the rehabilitated standard situation by network operators: 100 Points = 1.0 to 0 points = 6.0; computation by means of a non-linear function.
3 Assessment: 100% Passed tightness tests according to APS guideline = 1.0; a test series according APS guideline leaky = 4.4; from two test series according APS guideline leaky = 6.0.
4 Assessment: Demanded combine thickness kept = 1.0; composite thickness is not attained at individual points, but reaches the means, the demanded value = 3.0; demanded composite thickness predominantly not reached = 6.0.
5 Assessment: Demanded E-modulus in accordance with DIBt certification observed in three tests = 1.0; observed in 2 tests = 4.4; observed in only one or no tests observed = 6.0.
6 Assessment: Permissible 24-hr E-modulus in accordance with DIBt certification observed in three tests = 1.0; observed in 2 tests = 4.4; observed in only one or in no tests observed = 6.0.
7 Assessment: Demanded tightness in accordance with DIBt certification observed in three tests = 1.0; observed in 2 tests = 4.4; observed in only one or no tests observed = 6.0.
8 Assessment: Buoyancy damages did not occur in the test = risk conceivable, buoyancy damages occurred in the test = risk observed; buoyancy damages occurred in the test = risk to expect.
9 Attachment from the house connection line to the main sewage with an LCR brim, made of optical fibre reinforced polypropylene with silicate resin system type W (winter resin) under the use of a pipe rehabilitation device (LCR packer).
10 Assessment: Available = yes; not available = no; allowances/testimonies/proofs must apply to the materials used in the test.
* Grade calculation based on unrounded values

Assessment key of test results: Very gut = 1.0 - 1.5 good = 1.6 - 2.5 satisfactory = 2.6 - 3.5 adequate = 3.6 - 4.5 inadequate = 4.6 - 5.5. poor = 5.6 - 6.0.

Repair systems: Better than their reputation!

Test conduits in the IKT test facility

Surprisingly good results in the IKT „Repair Systems“ test

Partial repair or rehabilitation of drains and sewers enjoys an at best dubious reputation. The corresponding systems are considered unreliable in operation, and not particularly durable. IKT's most recent product test, on „Repair systems for main drains“, on the other hand, arrives at a more encouraging conclusion: five of the twelve systems analyzed received a „Good“ grade, four „Satisfactory“, and only three a „Sufficient“.

Repair techniques are used extremely frequently in Germany when there is a need to eliminate isolated conduit damage. They are then preferred, frequently for cost reasons, over the alternative rehabilitation options, those of complete renewal and section-by-section renovation. Throughout Germany, around 25% of drain and sewer damage are tackled by means of repair methods (renovation: 26%, renewal: 49%; source: DWA survey, 2004).

Repair systems under test

Twelve repair systems in current use, subdivided into three groups, were submitted to comparative testing:

1. Injection and grouting/pressure filling

- Janßen Riss- und Scherbensanierung (Janßen crack and fragmentation repair system), Umwelttechnik Franz Janßen GmbH
- KASRO 2 Komponenten-Verpresssystem (KASRO two-component pressure-filling system), ProKASRO Mechatronik GmbH
- KA-TE PMO-Verfahren (KA-TE PMO system), KA-TE PMO AG

2. Short liners

- 3P-Plus-Kurzliner (3P-Plus short liner), sikotec GmbH / JT-elektronik GmbH
- ALOCIT Kurzliner (ALOCIT short liner), ALOCIT Chemie GmbH
- K-LINER, Kuchem GmbH
- KM-Kurzliner (KM short liner), KMG Pipe Technologies GmbH
- Konudur Sewer Repair Kit (VP), MC-Bauchemie Müller GmbH & Co. KG
- Point-Liner®, Bodenbender GmbH

3. Internal sleeves

- Quick-Lock, UHRIG Kanaltechnik GmbH
- Quick-Lock mit einseitiger Aufbördelung (Quick-Lock flared at one end), UHRIG Kanaltechnik GmbH
- Stuttgarter Hülse (Stuttgart Sleeve), Haas GmbH & Co. KG

System operators examine the repair results

Clients and steering committee

This product test was financed by the environment ministries of the German states of Baden-Württemberg and North Rhine-Westphalia, and twenty-six municipal drain/sewer-system operators. The latter, in particular, are in need of neutral and independent evaluation of the available procedures, in order to provide a better basis for their investment decisions in future.

The participating municipalities formed a steering committee which met a total of eleven times and took all the central decisions. It decided, for example, which systems were to be tested, how the test program should be compiled, and which test criteria were to be taken as the basis. Finally, it also decided on the concluding award of grades.

Test program

The central elements of the test program are provided by the system suppliers' Quality Assurance and the system tests.

Example of „branching crack“ damage type in vitrified clay pipes

Manuals, training provisions, third-party supervision, environmental impact certificates and technical approval by the Deutsches Institut für Bautechnik (German Institute for Building Technology, a government body, German abbreviation: DIBt) were registered and evaluated, inter alia, for the Quality Assurance item.

Four test lines consisting of concrete and vitrified clay, with nominal diameters ranging from ND 200 to ND 600, and also an additional ND 400/600 oval-section concrete line where the corresponding system could be used, were set up in the IKT test facility for each system for the purpose of the system tests. Typical forms of damage, such as transverse and longitudinal cracking, spalling, fragmentation and leaking joints were artificially incorporated into these conduits. Precisely the same amounts and types of damage were assigned to all test participants, who were then instructed to repair it.

The rehabilitation target was that of restoring the tightness and correct functioning of the conduit. Each participant was responsible for deciding how to achieve this, i.e., planning, conception, surface pretreatment, repair and any necessary reworking. The only additional condition imposed was that the repairs had to be performed without trench working, i.e., via the end manholes of the test conduits. There was no time limit.

High-pressure cleaning operations of fifteen flushing cycles per repair point (flushing load from fifteen years of operation, assuming annual flushing) were performed after completion of the work, in order to simulate operating loadings. Slight to clear traces of the cleaning operation remained apparent at many repaired points during the subsequent inspection.

Function

The function test evaluates whether the conduit section's assuredness of disposal has been restored. Every repaired point was awarded a grade by the system operators on the criteria of visual appearance, stabilization/protection of the damaged point, and possible flow obstructions.

In the case of the short liners, the surface, in the base zone, at least, was generally slightly roughened. In individual cases, glass fibers were also exposed, or detachment of material and cracking had occurred. Annular gaps or edges in the boundary zones were also measured on individual short liners.

In the injection and grouting/pressure-filling group, detachment of material had occurred in some cases in the Janßen Riss- und Scherbensanierung, and in the KASRO 2 Komponenten-Verpresssystem. In most cases, such detachment of material was, it is true, of no importance for the sealing action of the repair and could be removed, but could also form obstructions to flow. In the case of the KA-TE PMO-Verfahren, small upturns on the edges of the resin bodies had occurred at a few points only.
Flushing damage, significant in some cases, in the form of indentations, was observed in the case of the Stuttgarter Hülse, for which an incorrect tooth setting based on the manufacturer's data had resulted in incorrect tensioning of the sleeve. Edges, in some cases significant, had also formed on some sleeves, due to remnants of resin.

The two Quick-Lock sleeve variants tested produced differing results: in the first model tested, with no flaring, defective teeth on the locking wheel were observed after high-pressure flushing. This caused declining tensioning of the sleeve, with a corresponding reduction in its internal diameter, and therefore leaks. The sleeve subsequently tested, flared at one end, did not exhibit damage of this type. In both variants, upturns of a few millimeters can occur in the overlap zone of the sheet, depending on gap formation.

Tightness

Before and after high-pressure cleaning, all the repair points were subjected to hydraulic pressure testing for tightness, at increasing pressure levels of between 0.05 and 0.5 bar. The test times at each pressure level were between 15 and 30 minutes. The verdict of „Tight" or „Not tight" was awarded in the case of the tightness tests following the high-pressure flushing operation (which was significant for evaluation by means of visual assessment of egress of water on the exterior side of the pipe at the point of repaired damage). Differentiation of the „Tightness" test criterion was made on the basis of the six test-pressure levels.

In the injection and grouting/pressure-filling group, all the repaired points relevant for assessment remained tight up to at least 0.1 bar in the case of the Janßen Riss- und Scherbensanierung and the KA-TE PMO-Verfahren. At the highest pressure level, only six of the twelve repaired points (Janßen Riss- und Scherbensanierung) and twelve of fifteen repaired points (KA-TE PMO-Verfahren) remained tight at the highest pressure level. In the case of the KASRO 2 Komponenten-Verpresssystem, on the other hand, eight of twelve repaired conduits were not tight at any pressure level. Difficulties had occurred with the pressure-filling operation during the repair operation, with the consequence that a number of damaged points had not been completely filled with the repair resin.
The results of tightness testing also varied greatly in the short liners group. The 3P-Plus Kurzliner and KM Kurzliner were significantly above the average, with a tightness rate of 11/12 and 9/11

Example of short liners without (top) and with (down) visible traces of high-pressure flushing

tight repaired points, respectively. The Konudur Sewer Repair Kit (VP) short liners, in which weak points within the GRP laminate resulted in leaks, passed the tightness test up to the highest pressure level only in two of twelve cases. The other three short liners systems tested were all in the mid-range.

The results obtained with the three internal sleeves tested were similarly dispersed: in the case of the Stuttgarter Hülse, for which, according to the manufacturer's information, an incorrect tooth dimension had inadvertently been used, thirteen of fifteen repaired points leaked at all pressure levels. Tightness at nine of twelve repaired points up to and including 0.5 bar and of one up to 0.1 bar was demonstrated for the Quick-Lock sleeve flared at one end, on the other hand. In the case of the Quick-Lock sleeve without flaring, five of twelve repaired points remained tight at pressure levels of between 0.05 bar and 0.5 bar after high-pressure cleaning.

Test results

It is apparent, all in all, that successful conduit rehabilitation using repair systems is possible in principle. Significant quality differences are apparent, however. The grades awarded in each system group range, for example, from „Good" to „Sufficient". The system tests performed in the IKT test lines (weighting: 85%) and the

Example of sleeve without (top) and with (down) visible traces of high-pressure flushing

system suppliers' Quality Assurance (weighting: 15%) were evaluated.

The best result in the injection and grouting/pressure-filling group, and simultaneously the best result in the entire test, was achieved by the KA-TE PMO-Verfahren, which received the grade „Good" (1.6), followed by the Janßen Riss- und Scherbensanierung, also with a grade of „Good" (2.3). The recently developed KASRO 2 Komponenten-Verpresssystem still exhibited significant need for optimization, and was awarded only a grade of „Sufficient" (4.0).

In the lead in the short liners group are the KM-Kurzlinerand 3P-Plus-Kurzliner, each with the grade of „Good" (2.2). The K-Liner (Grade: 2.8), the ALOCIT short liners (Grade: 2.9) and the Point-Liner® (Grade: 3.1) were all in the mid-range, with a grade of „Satisfactory". The Konudur Sewer Repair Kit (VP), a recent development with a significant requirement for optimization, failed to achieve a grade better than „Sufficient" (4.2).

A similar spread in the grades awarded was also apparent in the case of the internal sleeves: the modified Quick-Lock sleeve flared at one end achieved a „Good" (2.2), whereas the previously tested Quick-Lock sleeve without flaring received a „Satisfactory" (3.1). The Stuttgarter Hülse (Grade: 4.3) manifested significant weaknesses and is now no longer available in its present form for waste-water conduits but is, according to the manufacturer, instead now used in combination with a short liner.

All in all, all the systems exhibited various weaknesses and strengths. The three systems which were awarded only the grade of „Sufficient" can, in the development status as tested here, scarcely be recommended for practical use. The manufacturers of the three systems have, however, already reacted to the results of the test, with the consequence that further development work has been initiated, and that these systems are no longer available in the form as tested at IKT.

On-site execution decisive

Not only the material components and selection of the system, but also on-site execution, are decisive for the quality of a repair. This applies to all systems, irrespective of their evaluation within the test scope. All working operations, ranging from the conception of the repair, e.g., the length and number of layers of a short liner, via the type and scope of preparatory work, up to and including the actual repair operation and finishing work, can have a significant influence on subsequent quality.

There is, in principle, the risk with all the repair systems that important work may be hurried - or even omitted - on site, whether for reasons of time and/or cost, and differing quality standards at the various contractors, or as a result of this work not being expressly specified - and therefore not remunerated - by the client. This applies, in particular, to preparatory and support provisions, such as high-pressure flushing, cutting and milling work, and the withdrawal from service of conduit sections, the (lack of) satisfactory execution of which is not immediately apparent at the acceptance inspection of the completed repair.

The client can combat these factors by ensuring that, at the initial stage, the necessary preparatory work is included in the invitation to tender. In a second step, the materials used, the nature and scope of the preparatory work performed, and of the repair systems, can be monitored - on a random-sample basis, if necessary - in the context of site supervision. Otherwise, repair documentation, including images of the damaged point before starting work, after completion of

Example of injection/grouting without (top) and with (down) visible traces of high-pressure flushing

the preparatory work and after completion of the repair, should at least be required.

Product-improvement cycle stimulated

The aim of the IKT product test is that of comparatively evaluating the quality of repair systems, outlining potential for improvement and, simultaneously, stimulating corresponding market pressure, in order that the suppliers utilize these potentials. The drain/sewer system operator, as the client, is the person who stipulates the quality requirements for the products, and how the products perform on these criteria.

Four of the twelve systems tested have already been taken off the market as a result of the results obtained in these tests, or have been replaced by a modified system or a previously envisaged market launch postponed. Alternatives for two of the systems are already available on the market, and the two other systems are currently undergoing improvement.

Authors

Dipl.-Ing. (FH) Kathrin Harting
Dipl.-Ök. Roland W. Waniek
IKT - Institute for Underground Infrastructure
Gelsenkirchen, Germany

(Result tables on the following pages)

Table 1: IKT „Repair systems for main drains" product test

Injection and grouting/pressure-filling system


System tests in test lines:

- Repair of three points of damage in each case in four sand-covered ND 200/ND 300 vitrified clay test lines and ND 300/ND 600 concrete pipes with grease depositions
- Damage in vitrified clay: 1) spalling 20x20 cm, 2) extensive crack ramification across approx. 1 m length, 3) leaking socket with crown crack and spalling (d = 5 cm)
- Damage in concrete: 1) transverse crack, 2) longitudinal cracks in side zone and crown, starting from tapered end (l = approx. 1 m), 3) leaking socket with crown crack and spalling (d = 5 cm)

System type	**Grouting/Pressure-Filling Method**	**Injection Method**	
System supplier	**KA-TE PMO AG**	**Umwelttechnik Franz Janßen GmbH**	**ProKASRO Mechatronik GmbH**
System	**KA-TE PMO-Verfahren** 	**Janßen Riss- und Scherbensanierung** 	**KASRO 2 Komponenten-Verpresssystem** 
Resin system used	BASF CONCRESIVE® 1850 and EPOXSONIC® EX 1355	JaGoPur	Konodur Robopress 07 with Konodur Additive RP
IKT test verdict*	**GOOD (1.6)**	**GOOD (2.3)**	**SUFFICIENT (4.0)**
System tests in test lines (weighting 85%)	**Good (1.7)**	**Satisfactory (2.6)**	**Sufficient (4.2)**
Function[1] (50%)	2.0	3.5	4.2
Tightness[2] (50%)	1.3	1.6	4.2
System-suppliers' Quality Assurance3 (weighting 15%)	**Excellent (1.0)**	**Excellent (1.0)**	**Satisfactory (3.0)**
System manual (20%)	Yes	Yes	Yes
Training provisions (20%)	Yes	Yes	Yes
Third-party supervision (20%)	Yes	Yes	No
Environmental impact (10%)	Yes	Yes	Yes
DIBt approval (10%)	Yes	Yes	No
Test certificates (10%)	Yes	Yes	No
Back-tracing of supply route (10%)	Yes	Yes	Yes
Additional information: Impression gained from site investigations and test-line use	Practically-orientated handling and use	Practically-orientated handling and use	Difficulties with pressure-filling during test, system not mature for practical use
Suitability for oval concrete section, ND 400/6004	proven	not available	not available
Suitability for use with ingress of groundwater and external water pressure5	proven	not proven	not tested
Available for the diameters (information from supplier)	Round section: ND 150 - ND 800 Oval section: ND 300/450 - ND 600/900	Round section: ND 100 - ND 700 Oval section: not for use with oval section lines	Round section: ND 200 - ND 600 Oval section: not suitable for use with oval section
Potential for improvement	/	Removal of remnants of resin; modification of packer system to permit easier positioning	Prolonged resin-reaction time; optimization of resin feed-line changing; individual pressure-filling of damaged points; removal of remnants of resin
Remarks	/	/	System not longer available in this form

1 Evaluation of function by visual assessment by system operators on basis of point scores (30% weighting after completion; 70% weighting after HP cleaning): 100 points = 1.0 to 0 points = 6.0; arithmetical averaging and statement of points in grades using a linear function

2 Evaluation on basis of internal water-pressure tests after HP cleaning (visual checking for escape of water); grading depending on pressure level with no egress of water: 0.5 bar = 1.0 / 0.4 bar = 1.7 / 0.3 bar = 2.3 / 0.2 bar = 3.0 / 0.1 bar = 3.7 / 0.05 bar = 4.0 / not tight at any pressure = 6.0; Damage-type 2 (longitudinal cracks) in the concrete test lines were eliminated from the evaluation due to non-uniform cracking patterns

3 Evaluation: existent = yes and non-existent = no; approval/certificates/proof analyses must apply to the materials used in the test

4 Evaluation: „proven" = system tested in ND 400/600 concrete test line with three types of damage, both criteria „Tightness" and „Function" assessed as at least „Sufficient" (≤ 4.5) for each type of damage; „not proven1" = system tested and at least one repaired point assessed as poorer than „Sufficient" for at least one of the criteria of „Tightness" and „Function"; „not proven²" = the system is available for ND 400/600 concrete pipes, but the supplier did not use it in the test; „not available" = the system is not available for use in ND 400/600 concrete pipes

5 Evaluation: „proven" = system loaded in ND 300 vitrified clay test line with three leaking sockets with ingress of water and with external water pressure, and all repaired points exhibited no ingress of water upon internal inspection; „not proven" = system tested, at least one repaired point exhibited ingress of water upon internal inspection; „not tested" = system not tested

* Grade calculated using non-rounded off data

Key to test-result grades: Excellent = 1.0 - 1.5; Good = 1.6 - 2.5; Satisfactory = 2.6 - 3.5; Sufficient = 3.6 - 4.5; Deficient = 4.6 - 5.5; Insufficient = 5.6 - 6.0

Table 2: IKT „Repair systems for main drains“ product test

Short liners

System tests in test lines:

- Repair of three points of damage in each case in ND 200/ND 300 (jacketed) vitrified clay test lines and ND 300/ND 600 concrete pipes (exposed), all pipes with grease depositions
- Damage in vitrified clay: 1) spalling 20x20 cm, 2) extensive crack ramification across approx. 1 m length, 3) leaking socket with crown crack and spalling (d = 5 cm)
- Damage in concrete: 1) transverse crack, 2) longitudinal cracks in side zone and crown, starting from tapered end (l = approx. 1 m), 3) leaking socket with crown crack and spalling (d = 5 cm)

System supplier	sikotec GmbH / JT-elektronik GmbH	KMG Pipe Technologies GmbH	Kuchem GmbH	ALOCIT Chemie GmbH	Bodenbender GmbH	MC-Bauchemie Müller GmbH & Co. KG
System	3P-Plus-Kurzliner	KM-Kurzliner	K-LINER	ALOCIT Kurzliner	Point-Liner®	Konudur Sewer Repair Kit (VP)
						
Resin system used	3P resin	ARALDITE GY 240 BD, with ARADUR 16 BD, air expeller, curing agent	ARALDITE GY 250 BD, with ARADUR 16 BD	ALOCIT Resin® Alocan, with Peroxan BP 50+ (curing agent)	Multi - PL® resin	Konudur 266 SR (VP)
IKT test verdict*	**GOOD (2.2)**	**GOOD (2.2)**	**SATISFACTORY (2.8)**	**SATISFACTORY (2.9)**	**SATISFACTORY (3.1)**	**SUFFICIENT (4.2)**
System tests in test lines (weighting 85%)	**Good (2.4)**	**Good (2.2)**	**Satisfactory (3.1)**	**Satisfactory (3.3)**	**Satisfactory (3.4)**	**Sufficient (4.3)**
Function[1] (50%)	3.3	2.4	2.3	2.6[9]	3.0	3.6
Tightness[2] (50%)	1.4	2.0[6]	2.9[7]	4.0[8]	3.9	5.0
System-suppliers' Quality Assurance[3] (weighting 15%)	**Excellent (1.0)**	**Good (2.0)**	**Excellent (1.5)**	**Excellent (1.0)**	**Excellent (1.0)**	**Sufficient (4.0)**
System manual (20%)	Yes	Yes	Yes	Yes	Yes	Yes
Training provisions (20%)	Yes	Yes	Yes	Yes	Yes	No
Third-party supervision (20%)	Yes	Yes	Yes	Yes	Yes	No
Environmental impact (10%)	Yes	Yes	Yes	Yes	Yes	Yes
DIBt approval (10%)	Yes	No	No	Yes	Yes	No
Test certificates (10%)	Yes	No	Yes	Yes	Yes	No
Back-tracing of supply route (10%)	Yes	Yes	Yes	Yes	Yes	Yes
Additional information: Impression gained from site investigations and test-line use	Practically-orientated handling and use, extremely extensive cutting work in test	Practically-orientated handling and use	Practically-orientated handling and use	Practically-orientated handling and use	Practically-orientated handling and use	Practically-orientated handling and use
Suitability for oval concrete section, ND 400/600[4]	not proven[2]	not available	not available	not proven[1]	not proven[2]	not available
Suitability for use with ingress of groundwater and external water pressure[5]	proven	proven	not tested	not tested	not tested	not tested
Available for the diameters (information from supplier)	Round section: ND 100 - ND 700 Oval section: ND 250/375 - ND 500/750	Round section: ND 150 - ND 600 Oval section: not used	Round section: ND 100 - ND 1000 Oval section: not used	Round section: ND 100 - ND 800 Oval section: ND 200/300 - ND 500/750	Round section: ND 100 - ND 1200 Oval section: ND 250/375 - ND 400/600	Round section: ND 100 - ND 800 Oval section: not used
Potential for improvement	Improve flushing resistance	Three-layer installation in case of missing wall elements, even in small NDs	Improve flushing resistance (possibly with three-layer short liner)	Increase resin viscosity; possibly: increase scope of preparatory work	Improve sealing action	Improve laminate's sealing action and flushing resistance
Remarks	/	/	/	/	Use of an additional PES nonwoven in all NDs	System no longer available

1 Evaluation by visual assessment by system operators on basis of point scores (30% weighting after completion; 70% weighting after HP cleaning): 100 points = 1.0 to 0 points = 6.0; arithmetical averaging and statement of points in grades using a linear function; averaging of the grade averages for the vitrified clay and concrete test lines
2 Evaluation on basis of internal water-pressure tests after HP cleaning (visual checking for escape of water); grading depending on pressure level with no egress of water: 0.5 bar = 1.0 / 0.4 bar = 1.7 / 0.3 bar = 2.3 / 0.2 bar = 3.0 / 0.1 bar = 3.7 / 0.05 bar = 4.0 / not tight at any pressure = 6.0; Damage-type 2 (longitudinal cracks) in the concrete test lines were eliminated from the evaluation due to non-uniform cracking patterns
3 Evaluation: existent = yes and non-existent = no; approval/certificates/proof analyses must apply to the materials used in the test
4 Evaluation: „proven" = system tested in ND 400/600 concrete test line with three types of damage, both criteria „Tightness" and „Function" assessed as at least „Sufficient" (≤ 4.5) for each type of damage; „not proven1" = system tested and at least one repaired point assessed as poorer than „Sufficient" for at least one of the criteria of „Tightness" and „Function"; „not proven²" = the system is available for ND 400/600 concrete pipes, but the supplier did not use it in the test; „not available" = the system is not available for use in ND 400/600 concrete pipes
5 Evaluation: „proven" = system loaded in ND 300 vitrified clay test line with three leaking sockets with ingress of water and with external water pressure, and all repaired points exhibited no ingress of water upon internal inspection; „not proven" = system tested, at least one repaired point exhibited ingress of water upon internal inspection; „not tested" = system not tested
6 Damage-type 3, vitrified clay, ND 200 not evaluated, due to not sufficiently clear test result
7 Damage-type 1, vitrified clay, ND 200 and Damage-type 3, vitrified clay, ND 300, not evaluated due to cracking additional to the basis damage-type, with unclear causes
8 Damage-type 3, vitrified clay, ND 200 not evaluated due to cracking additional to the basic damage-type, with unclear causes
9 Damage-type 1, vitrified clay, ND 300 not evaluated, due to covering of end of short liner as a result of unplanned positioning error (overlapping) by the repair contractor (applies to the first-laid end in FR and the end subjected to greater loads during HP cleaning)
* Grade calculated using non-rounded off data

Key to test-result grades: Excellent = 1.0 - 1.5; Good = 1.6 - 2.5; Satisfactory = 2.6 - 3.5; Sufficient = 3.6 - 4.5; Deficient = 4.6 - 5.5; Insufficient = 5.6 - 6.0

Table 3: IKT „Repair systems for main drains“ product test

Internal sleeves

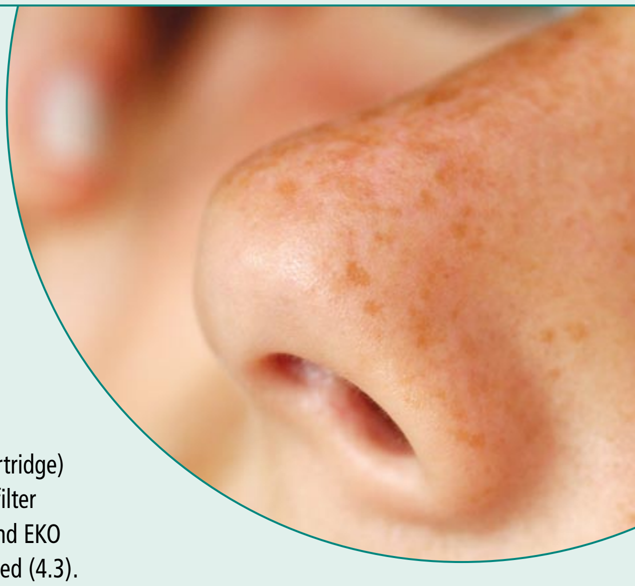
System tests in test lines:

- Repair of three points of damage in each case in ND 200/ND 300 (jacketed) vitrified clay test lines and ND 300/ND 600 concrete pipes (exposed), all pipes with grease depositions
- Damage in vitrified clay: 1) spalling 20x20 cm, 2) extensive crack ramification across approx. 1 m length, 3) leaking socket with crown crack and spalling (d = 5 cm)
- Damage in concrete: 1) transverse crack, 2) longitudinal cracks in side zone and crown, starting from tapered end (l = approx. 1 m), 3) leaking socket with crown crack and spalling (d = 5 cm)

System supplier	UHRIG Kanaltechnik GmbH	UHRIG Kanaltechnik GmbH	Haas GmbH & Co. KG
System	Quick-Lock flared at one end 	Quick-Lock 	Stuttgarter Hülse 
Sealing system used	EPDM rubber seal	EPDM rubber seal	Grouting Compound 03567L51
IKT test verdict*	**GOOD (2.2)**	**SATISFACTORY (3.1)**	**SUFFICIENT (4.3)**
System tests in test lines (weighting 85%)	Good (2.4)	Satisfactory (3.4)	Sufficient (4.3)
Function[1] (50%)	2.9	3.1	3.6
Tightness[2] (50%)	1.9	3.7	5.1
System-suppliers' Quality Assurance3 (weighting 15%)	**Excellent (1.5)**	**Excellent (1.5)**	**Sufficient (4.0)**
System manual (20%)	Yes	Yes	Yes
Training provisions (20%)	Yes	Yes	No
Third-party supervision (20%)	Yes	Yes	Yes
Environmental impact (10%)	Yes	Yes	No
DIBt approval (10%)	Yes	Yes	No
Test certificates (10%)	Yes	Yes	No
Back-tracing of supply route (10%)	No	No	No
Additional information: Impression gained from site investigations and test-line use	Practically-orientated handling and use	Practically-orientated handling and use	Practically-orientated handling and use Pressure prefilling of all damage in test
Suitability for oval concrete section, ND 400/600[4]	not available	not available	not proven[1]
Suitability for use with ingress of groundwater and external water pressure[5]	proven	not tested	not tested
Available for diameters (information from supplier)	Round section: ND 150 - ND 800 Oval section: not used	Round section: ND 150 - ND 800 Oval section: not used	Round section: ND 70 - ND 2000 Oval section: up to ND 900/1350
Potential for improvement	Reduce edges in overlap zone	Improve flushing resistance, improve hydraulic properties of sleeve	Improve tensioning of sleeve and sealing action
Remarks	/	/	System no longer available for this application

1 Evaluation of function by visual assessment by system operators on basis of point scores (30% weighting after completion; 70% weighting after HP cleaning): 100 points = 1.0 to 0 points = 6.0; arithmetical averaging and statement of points in grades using a linear function
2 Evaluation on basis of internal water-pressure tests after HP cleaning (visual checking for escape of water); grading depending on pressure level with no egress of water: 0.5 bar = 1.0 / 0.4 bar = 1.7 / 0.3 bar = 2.3 / 0.2 bar = 3.0 / 0.1 bar = 3.7 / 0.05 bar = 4.0 / not tight at any pressure = 6.0; Damage-type 2 (longitudinal cracks) in the concrete test lines were eliminated from the evaluation due to non-uniform cracking patterns
3 Evaluation: existent = yes and non-existent = no; approval/certificates/proof analyses must apply to the materials used in the test
4 Evaluation: „proven“ = system tested in ND 400/600 concrete test line with three types of damage, both criteria „Tightness“ and „Function“ assessed as at least „Sufficient“ (≤ 4.5) for each type of damage; „not proven1“ = system tested and at least one repaired point assessed as poorer than „Sufficient“ for at least one of the criteria of „Tightness“ and „Function“; „not proven²“ = the system is available for ND 400/600 concrete pipes, but the supplier did not use it in the test; „not available“ = the system is not available for use in ND 400/600 concrete pipes
5 Evaluation: „proven“ = system loaded in ND 300 vitrified clay test line with three leaking sockets with ingress of water and with external water pressure, and all repaired points exhibited no ingress of water upon internal inspection; „not proven“ = system tested, at least one repaired point exhibited ingress of water upon internal inspection; „not tested“ = system not tested
* Grade calculated using non-rounded off data

Key to test-result grades: Excellent = 1.0 - 1.5; Good = 1.6 - 2.5; Satisfactory = 2.6 - 3.5; Sufficient = 3.6 - 4.5; Deficient = 4.6 - 5.5; Insufficient = 5.6 - 6.0



Odour-filter: no smell capacity

IKT product test „odour-filter"

Odour-filter for sewer manholes under test: None of the candidates was able to convince throughout in the system test. That is the central result of the latest IKT product test. The IKT - Institute for Underground Infrastructure examined six odour-filters for sewer manholes for effectiveness in collaboration with partner institutes.

The IKT tested six odour-filters for sewer manholes on behalf of eleven sewage network operators. In four focuses of investigation, the products had to prove their worth: system test, handiness, quality assurance of the supplier and in-situ-investigations. The results still allow space for improvements.

On the test stand: The filters had to prove their effectiveness in numerous measurements – what not all could succeeded in

None of the test candidates got beyond the overall assessment „satisfactory". Less glossy winner is the COALSI® Geruchssperre BN 00.2001.0K (Hybrid) (smell barrier) with the grade 2.8. Similarly, grade was attained by the Kanalschachtfilter FIS 0600 (sewage shaft filter) of ROMOLD GmbH (grade 3.0). The UGN® Hybrid-Kanalschachtfilter Standard 170032 (sewage shaft filter) attained grade 3.5. The products belflor®-Biofilterpatrone FIP 700 (organic filter cartridge) attained grade (3.6), belflor®-Aktivkohlefilter AKTIVFIP (activated carbon filter) (3.8) and EKO Biofilter Typ KF-400 (organic filter) attained (4.3).

Hindrance to ventilation

If the odour-filter hinders the manhole ventilation, the smell can be diverted to other manholes. Moreover, the IKT test staff fear intensified corrosion through hydrogen sulphide in such cases in concrete buildings. In a large part of the investigated odour-filters, insufficient flow-through possibility was detected. Only belflor®-Aktivkohlefilter AKTIVFIP (grade 2.5) and COALSI® Geruchssperre BN 00.2001.0K (Hybrid) (3.1) show acceptable values in this central test criterion.

Reducing sewage smell

In the second central test criterion, the smell efficiency, the test staff found clear differences. The Kanalschachtfilter FIS 0600 of ROMOLD attains the best result here with a large gap (grade 1.7) evidently at the expense of flow-through capability. The use with the highest air throughput (belflor®-Aktivkohlefilter AKTIVFIP) features the smallest smell efficiency (grade 5.5). The remaining candidates obtain satisfactory and adequate assessments.

Different filter capacity

Also with the chemical determination of material concentrations, the candidates were examined for their cleaning capacity. Five of the six tested filters attained a relatively high efficiency in the retention of hydrogen sulphide (at least „adequate"); the belflor®-Aktivkohlefilter AKTIVFIP attained a below average grade. All four products with organic filter or hybrid filter featured at least an „adequate" cleaning capacity regarding the gas component - ammonia - both pure activated carbon filters were „poor". With the retention of Dimethyl disulphide and limonene, especially the organic filters had difficulties. Altogether the filter from ROMOLD (grade 2.2) and the COALSI® Geruchssperre BN 00.2001.0K (Hybrid) (2.5) have the best cleaning capacity in comparison.

Good to handle

The network operators involved in the product test were interested also in its handiness besides the function of the odour-filter. A test installation in three different manholes on the test compound of the IKT in Gelsenkirchen gave information about the fitting accuracy. The weight of the systems that also flowed into the assessment did not at all pose impairment to handiness. In addition, the installation did not appear to be difficult.

In the practice test: A technician installs odour-filters in manholes on the IKT compound

Weakness in fitting accuracy

The test staff found partial considerable lack of leakage tightness between filter housing and manhole wall. The effectiveness of the filter can as such be diminished clearly. The leakage quantities were measured and included in the assessment. In some odour-filters, the dirt trap could no longer be fitted in properly after the installation.

What are effective alternatives?

In addition to the odour-filters, further products were tested in this product test, which is considered in the practice mostly as simple and economical alternatives. Ventilation and corrosion risks seem ruled out in contrast to the odour-filters. Products from manufacturers like Biothys und Clemens & Dupont release active agents that should fight rising smells. Grades were not allocated because readings cannot be interpreted based on unknown material mixtures. The exact manner of action was not comprehensible in the test. Subjective observations in the tests, however, suggest smell-diminishing or changing effect.

Conclusion of the test staff

None of the tested odour-filters was able to convince generally in the criteria of the system test. Only one product showed both in the flow-through capacity as well as in the cleaning capacity at least adequate results. The quality assurance of the product supplier is very good with an exception. Assembly and installation are possible in all models, without great effort. In the fitting accuracy of manhole inserts, there is still need to catch. Products that release the tested active agents can be a remarkable alternative, according to engineers' assessment at least in an individual case.

The latest product test of the IKT reveals clear weaknesses of the odour-filter in central functions. The manufacturers are now demanded to improve the flow-through capability, sealing to the manhole and in some cases also the filter capacity of its products.

Background

Especially in summer months, smell emissions lead from the sewage system leads to odours irritation. Increased complaints from citizens are received as such by the communities. The sewage network operators increasingly use odour-filters in the respective sewer manholes, in such cases. In order to acquire information about their mode of operation and efficiency, the IKT was commissioned with the test of selected products.

Evaluation criteria

The system tests were evaluated in the test stand (weighting 80 percent), the quality assurance of the product's supplier (weighting 10 percent), as well as the handiness (weighting 10 percent). Evaluation criteria of system tests were flow-through capability, smell efficiency, as well as efficiency of material retention.

Test program

The odour-filters were subjected to an extensive test program. On a test stand, leakage quantity measurements were carried out initially at the institute for water economy of the University of the Federal Armed Forces (Bundeswehr) Munich. Then the investigation of air flow-through capability was carried out.

In the end, tests were carried out at the institute for settlement, water quality, and refuse economy (ISWA) of the University of Stuttgart, with respect to cleaning capacity. In addition, a synthetic, smell-intensive exit sewage air was produced on the same test stand. Based on the substrate and smelling material concentrations in raw and pure gas, the substrates and/or smell reduction effect could then be evaluated.

In the investigations of odour-filters for handiness, the weight, the fitting accuracy, and leakage quantity stood on the foreground.

In-situ-investigations of the involved network operators as well as the University of Kassel supplemented the test program. Measurements on sewer manholes by the University of Kassel served especially to review the approach in system tests and the results obtained there for plausibility.

For further findings, most of the tested products in manholes of the involved network operators were used to investigate handiness and operational suitability under practice conditions.

Results available on the Internet

The detailed final report of the IKT product test „odour-filter" is ready on the Internet for download free of charge:
www.ikt.de

Author

Dipl.-Ing. Thomas Brüggemann,
IKT - Institute for Underground Infrastructure

(Result table on the following page)

Systems in the IKT product test – odour-filters 2010

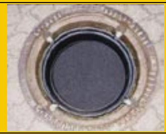
Manufacturer	Filters
COALSI®	COALSI® Geruchssperre BN 00.2001.0K (Hybrid) (smell barrier)
ROMOLD GmbH	ROMOLD Kanalschachtfilter FIS 0600 (sewage shaft filter)
Störk Umwelttechnik GmbH	belflor®-Biofilterpatrone FIP 700 (organic filter cartridge)
	belflor®-Aktivkohlefilter AKTIVFIP (activated carbon filter)
UGN – Umwelttechnik GmbH	UGN® Hybrid-Kanalschachtfilter Standard 170032 (sewage shaft filter)
Warwas	EKO Biofilter Typ KF-400 (organic filter)

Products that release active agents in the supplementary investigation

Manufacturer	Product
Biothys	Gelly mat Gelactiv® SHK-P and/or NHK-P
Clemens & Dupont OHG	C&D Brick

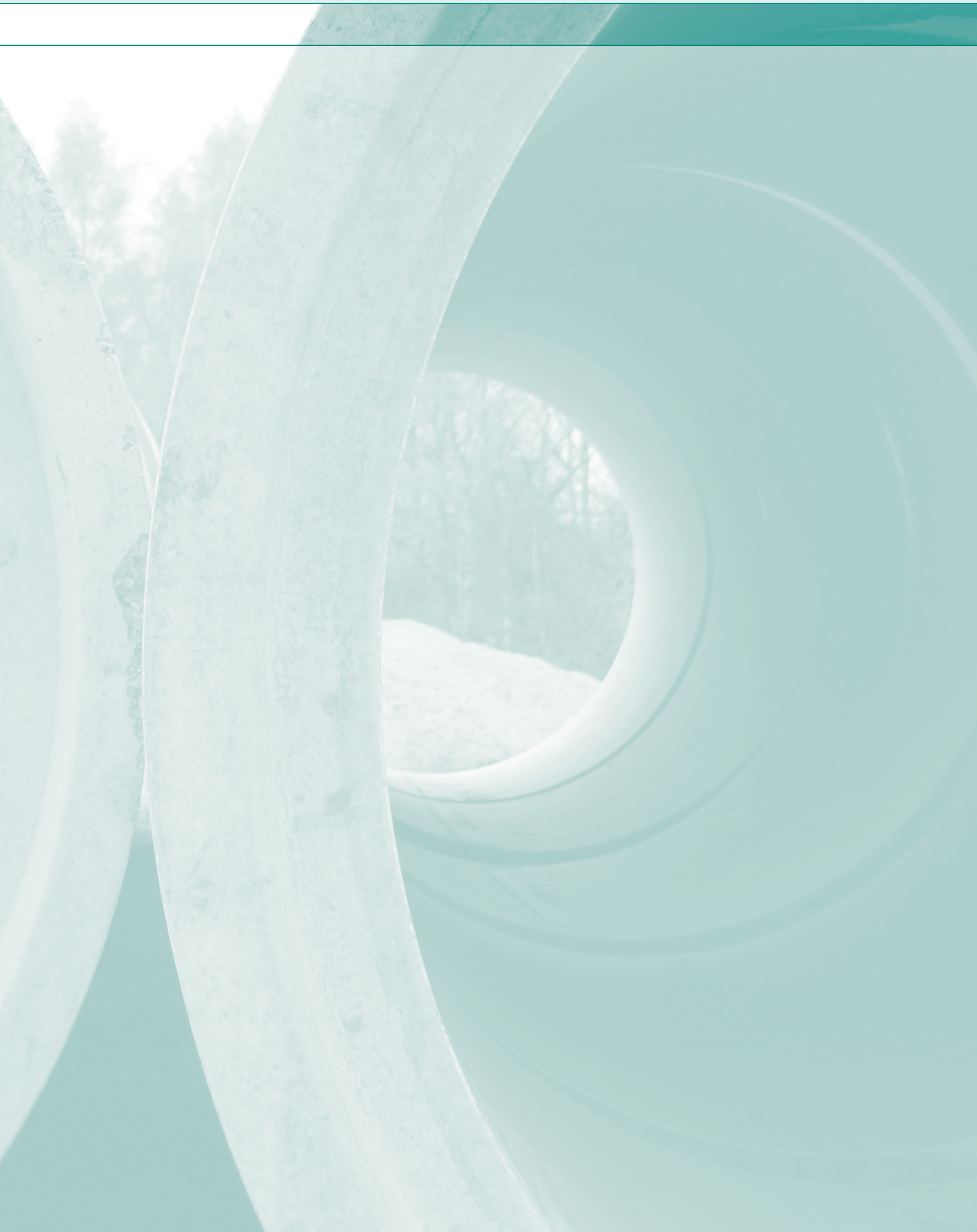
IKT product test „Odour-filter“

Installation situation (system tests): Plastic shaft with class D 400 shaft cover according to DIN EN 124 and shaft frame made of cast iron - form C according to DIN 19584-2

Product supplier	COALSI®	ROMOLD GmbH	UGN – Umwelttechnik GmbH	Störk Umwelttechnik GmbH	Störk Umwelttechnik GmbH	Warwas
Product	COALSI® Geruchssperre BN 00.2001.0K, Hybrid	Kanalschachtfilter FIS 0600	UGN® Hybrid-Kanalschachtfilter Standard 170032 (2001-oxi-1.0)	belflor®-Biofilterpatrone FIP 700	belflor®-Aktivkohlefilter AKTIVFIP	EKO Biofilter Typ KF-400
						
Type of filter	Hybrid filter	Active carbon filter	Hybrid filter	Organic filter	Active carbon filter	Organic filter
IKT test mark	**SATISFACTORY (2.8)**	**SATISFACTORY (3.0)**	**SATISFACTORY (3.5)**	**ADEQUATE (3.6)**	**ADEQUATE (3.8)**	**ADEQUATE (4.3)**
System tests on test stand (weighting 80%)	**satisfactory (3.1)[1]**	**satisfactory (3.3)**	**adequate (4.1)**	**adequate (4.0)**	**satisfactory (4.2)[4]**	**inadequate (4.7)**
Efficiency - flow-through capability[3] (40%)	3.6[4]	5.5	5.4	5.1	2.5[5]	5.2
Smell efficiency[6] (40%)	2.9	1.7	2.9	2.9	5.5	4.5
Efficiency - material retention[7] (20%)	2.5	2.2	3.7	4.2	5.1[8]	4.3
Hydrogen sulphide (45%)	1.9	1.8	2.6	3.9	4.7	4.2
Dimethyl-disulphide (30%)	2.6	1.4	5.5	4.7	5.6	4.6
Ammonia (15%)	3.6	5.5	2.5	3.3	5.0	3.5
Limonene (10%)	3.2	1.7	5.7	5.0	5.4	5.3
System suppliers' quality assurance (weighting 10%)	**very good (1.0)**	**very good (1.0)**	**very good (1.0)**	**very good (1.0)**	**very good (1.0)**	**satisfactory (3.5)**
Completeness of the installation and maintenance description[9] (50%)	yes	yes	yes	yes	yes	yes
Measures for guaranteeing constant quality of filter materials[10] (40%)	yes	yes	yes	yes	yes	no
Recommendations on disposal suitability of filter materials[11] (10%)	yes	yes	yes	yes	yes	no
Handling suitability (weighting 10%)	**good (2.4)**	**good (2.2)**	**good (1.7)**	**satisfactory (2.6)**	**satisfactory (3.3)**	**good (2.1)**
Fitting accuracy / installation (80%) – Optical impression[12] (50%)	2.7	3.5	1.8	1.8	1.8	3.5
Fitting accuracy / installation (80%) – Share of leakage amount[13] (50%)	2.7	1.6	1.4	3.4	6.0[14]	1.1
Weight[15] (20%)	1.0	1.0	2.3	2.7	1.0	1.3
Additional information: Impression from in-situ investigations of network operator	seepage leaks during the installation in shaft frames made of cast iron with concrete (BEGU); constructive deviations from filter model from system tests (e.g. hook-in noses)	a fold-bracket of the clamp ring prevents proper insertion of dirt catcher (consequence: clogged gully); difficulties in adapting the clamp ring on existing shaft neck	stiff and/or inflexible arrangement of the hook-in angle leads, where appropriate, problems during insertion into the shaft	Seal slips and/or rotates when fit into the assembly ring	*no in-situ investigations, due to construction features comparable with the belflor® organic filter cartridge FIP 700*	Dirt trap could not be incorporated
Installation time[16]	2 min	3 ½ min	2 ½ min	2 min	2 min	1 min
Service life / durability of filter materials (accord. to supplier)[17]	active coal mat: 2 ½ – 3 years hybrid filter mat: no information	2 Years	no information	4 – 6 Years	no information	3 Years
Tolerance area for shaft entry opening DN 625 (accord. to supplier)[17]	no information	595 mm to 645 mm	no information	610 mm to 630 mm	610 mm to 625 mm	no information
Available for shaft entry opening with diameter (accord. to supplier)[17]	650 mm, 800 mm	-	DN 560, DN 600, DN 800	-	-	625 mm
Recommended improvements	offer standard seal for BEGU shaft frame; standardise construction features (e.g. hook-in noses, seal)	improve flow-through capability; optimize fitting accuracy for dirt trap; handling capability of clamp ring	improve flow-through capability; flexibility of hook-in angle improve	improve flow-through capability; improve material retention; Fix sealing element	Improve cleaning capacity; improve sealing to the shaft wall; fix sealing element	improve flow-through capability; improve cleaning capacity; fitting accuracy improve dirt trap

1 In the test stand for system tests a shaft frame with interior cavity (cast iron frame form C according to DIN 19584-2 was used. The system tests were carried out for this reason by means of an adapter ring that is offered by the manufacturer COALSI® expressly for this type of shaft frame. In shaft frames made of cast iron and concrete (BEGU) adapter ring is forgone according to manufacturer. In this case, no other sealing element finds application, in accordance the manufacturer.
2 The system test for cleaning capacity (smell efficiency, material retention efficiency) resulted on a filter housing with a sealing that was modified by test personnel - in consultation with the manufacturer. The filter housing hence does not correspond with the delivered standard condition.
3 The efficiency of flow-through capability is the percentage share of the filter throughput Q_F from reference volumetric flow Q_B (shaft without filter). Assessment: Efficiency of flow-through capability 67% = 1.0 to efficiency of flow-through capability 0% = 6.0; grades are computed through a linear function. Average value computation from 10 individual grades in shaft excess pressure Δp = 5, 10, 20, 25, 50 Pa respectively with a dry and with damp air.
4 Average value computation from 2 individual grades at shaft excess-pressure Δp = 2.4 Pa respectively with dry and with damp air, because filter throughput of practice-relevant maximum values was already reached under these pressure conditions.
5 Average value computation from 2 individual grades in shaft excess-pressure Δp = 2.4 Pa respectively with dry and Δp = 4.9 Pa with damp air because filter throughput of the practice relevant maximal values was already reached in these pressure conditions.
6 Smell efficiency: Percentage reduction of smell material concentration (GE/m³) of the gas mixture of hydrogen sulphide, DMDS, ammonia and limonene in air volume flow of 20 m³/h; assessment: Smell efficiency 100% = 1.0 to smell efficiency 0% = 6.0. Grade computation by means of a linear function
7 Efficiency of material retention: Percentage reduction of the substrate concentration of individual gas components (ppm); average value computation of efficiency of material retention out of 4 individual values in air volume flow of 1 m³/h, 5 m³/h, 20 m³/h and 50m³/h. Efficiency of material retention 100% = 1.0 to efficiency of material retention 0% = 6.0; computation of grades through a linear function
8 Average value computation of efficiency of material retention out of 3 individual values in air volume flow of 5 m³/h, 20 m³/h and 50 m³/h. Material retention in air volume flow of 1 m³/h could not be measured technically.
9 Completeness of installation and maintenance description; Assessment: complete = yes; incomplete = no
10 Measures for guaranteeing constant quality of filter materials can be presented in a comprehensible manner (incl. proof documents): yes; no
11 Recommendations for disposal suitability of the filter materials offer sufficient help to the user: yes; no
12 Assessments of the visual effect with respect to fitting accuracy: (++++++) = 1.0; (+++++ -) = 1.8; (++++ - -) = 2.7; (+++ - - -) = 3.5; (++ - - - -) = 4.3; (+ - - - - -) = 5.2; (- - - - - -) = 6.0
13 Assessment of the share of leakage amount in the total volume flow QL / (QF+QL): 0% = 1.0 to 50% = 6.0; computation of grades through a linear function.
14 Computation of grades based on mathematically determined leakage quantity because no realizable measuring result (additional seal, which is not component of the filter system, had to be mounted to enable testing)
15 Assessment of the weight (effective load): ≤ 5 kg = 1.0; 5 kg = 1.0 to <25 kg = 4.5 (computation of grades through linear function) ≤ 25 kg = 6.0
16 Installation time: Average of three installation processes (installation process 1: Person A, untrained, standard shaft; installation process 2: Person B, untrained, extreme shaft; installation process 3: Person B, practiced, standard shaft)
17 Referred to in the documents of manufacturer (installation and maintenance descriptions, product descriptions on the Internet homepage of the manufacturer, pamphlets and prospectuses of the manufacturer), which were obtained within the scope of product test
* Grade calculation based on unrounded value

Key to test-result grades: Excellent = 1.0 - 1.5; Good = 1.6 - 2.5; Satisfactory = 2.6 - 3.5; Sufficient = 3.6 - 4.5; Deficient = 4.6 - 5.5; Insufficient = 5.6 - 6.0



What does IKT do?

The IKT is a neutral, independent, and non-profit institute. It works practice and application oriented on questions of the underground pipeline construction. Focus is the sewer system. The IKT carries out research projects, inspections, product tests, consultations, and seminar for construction, operation, and rehabilitation of underground infrastructures.

Operators of public and private pipeline networks are the main target group. The fields of operation of the IKT are oriented in first place towards questions and problems of the network operators. This comes from the foundation contract of the institute dating back to the year 1994, namely to acquire scientifically grounded expertise for an economic, technically innovative, environmentally as well as citizen friendly construction, rehabilitation and maintenance of pipeline networks. For companies from the industrial sector, the IKT performs further support activities in test and trial of new products and procedures.

The fields of activity of the IKT are in details:

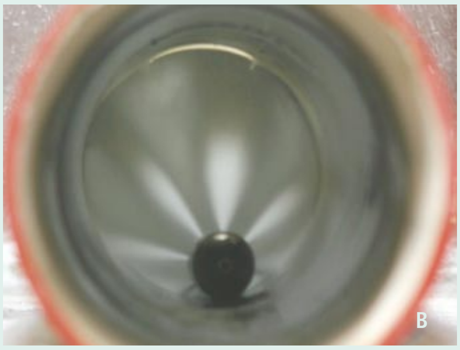
- Practice-oriented research
- construction supervision, material testing and flow measurement
- Comparative product tests
- Consultation and expert opinion

Practice-oriented research

The application related research of the IKT serves predominantly to solve questions of the network operators. The IKT is permanently in close contact with them to grasp problems and open questions. Network operators steering committees accompany all IKT research projects. Members of the steering groups select the products to be investigated, determine tests boundary conditions, and directly informed regularly about current findings and developments.

Hydraulic cylinder in the IKT large scale test facility

IKT jacking simulator, ND 1600


A View into a sewer manhole
B HP nozzle in sewer
C Root grown into the sewer

In research projects, a thorough analysis of the problem definition is done first. Subsequently, practical solutions are worked out, implemented in pilot construction sites or flow in to action instructions and recommendations for network operators.

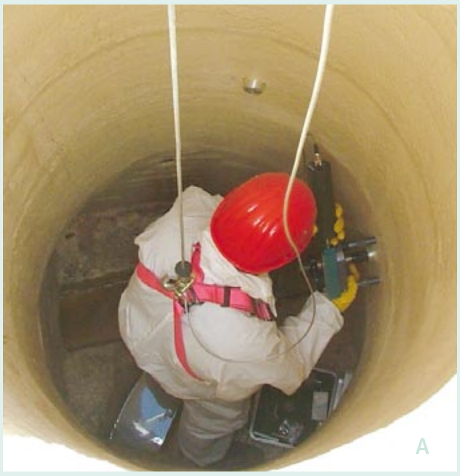
Research subjects:
- Sewer operation
- Sewer cleaning
- Estate draining
- Sewer rehabilitation
- Sewer manholes
- Sewer construction
- Pipe-jacking
- Root ingrowths

Construction supervision, material testing, and flow measurement
The expertise of IKT research flows over short paths into further activities of the institute.

The IKT offers network operators quality assuring practical product and system tests, construction supervision, flow comparison measurements on sewage treatment plants, rain basin and reservoir channels, calibration of flow and control equipment as well as tests according to self-diagnostic ordinances of the States.

The three test bodies of the IKT

Test body for construction products	Test body for flow measurements	Test body for water-permeable surface coatings
Accredited DAP-PL-443.00 **DIBt-recognised** • Test, supervision and certification body	**Nationally recognised** • according to EKVO Hessen • according to SüwV Kom NRW	**DIBt-designated**
Main focus • Material test (plastics, concrete, vitrified clay, tube liner) • Construction supervision • Quality assurance (e.g. of sewer and manhole rehabilitations) • Test institute for construction supervisory certifications of the DIBt	**Main focus** • Comparative measurements on sewage treatment plants, rain basin, reservoir channels • Calibration of flow measuring and control devices • Tests according to SüwVKan and SüwV-Kom • Extraneous water determination • Expert opinion	**Main focus** • Suitability test of surface coatings • Verification of water permeability • Determination of pollutant retention • DIBt certification test



A Adhesive pull test on a coated manhole
B Crown pressure test
C Flow measurement

In addition, first and suitability tests, standard material tests, technical approval by the Deutsches Institut für Bautechnik (German Institute for Construction Technology, a government body, German abbreviation: DIBT), individually coordinated special tests, as well as supporting tests in procedure development can be carried out for product manufacturers.

Comparative product tests

A particular specialty of the IKT is comparative product tests in which products and procedures are tested thoroughly under laboratory and practice conditions. Every product test is run by a group of network operators. Decisions on test contents, processes and criteria as well as the conclusive assessment are made by the group jointly in a control panel. Thus, it is guaranteed that the tests run practically, neutrally and independently of company interests.

The results deliver solid and reliable information about strengths and weaknesses of the products offered to network operators on the market. Therefore, they can make their purchase decisions based on facts instead of on manufacturer advertisement. At the same time the IKT product tests offer the suppliers criteria for improvement of tested products and procedures and thus also to strengthen their market position.

Consultation and expert opinion

On the basis of findings from the fields of research, inspection and testing, the IKT offers support services for sewer network operators, which are oriented towards individual questions of network operators (e.g. construction site analyses, feasibility studies, presentation and mediation, techno-economic assessments, economic-social costs analyses). In addition, scientifically well-grounded expert opinions are offered, to which courts, public and private network operators, construction companies, product manufacturers and engineering offices (e.g. damage expert opinions, court expert opinions, out-of-court settlements) can fall back. The following gives an overview of concrete consultation services in individual competency areas:

Sewer cleaning/operation

practice day in sewer operation, checking of tender documents, assessment of damages due to sewer cleaning (e.g. back-up, cellar flooding etc.), cause analysis of cleaning damages to sewage pipelines, analysis of malfunction (drain hindrances, clogging), assessment of cleaning strategies, recommendations for protective sewer cleaning, compilation of market surveys, recommendations for high pressure flushing resistance of pipe products, organisation and presentation of regional interest associations of network operators, optimisation of reporting

Consultation services of the IKT

New sewer construction

closed method of construction (pipe-jacking), open method of construction (timbering, pipe trench), static calculations (stability), drilling core removal and test (material test), damage documentation and assessment, recording and evaluation of the actual construction measures

Construction of a pipeline network in the IKT large scale test facility

Network operators appraise dismantled testing bodies

Manhole rehabilitation
selection of rehabilitation procedure, quality assurance of rehabilitation measures, recording and assessment of rehabilitation quality, analysis and evaluation of rehabilitation damages, practical suitability test of rehabilitation systems

Sewer rehabilitation
quality assurance of rehabilitation measures, recommendations for the use of modern materials in sewer rehabilitation (especially plastics), tube liner, part liner and coating methods, analysis and examination of rehabilitation damages

Estate draining
closed method of construction (rehabilitation of connection points and pipelines), open method of construction (pipe laying, connection to main sewer systems), malfunction (drain hindrances, clogging), damage documentation and evaluation, recording and evaluation of actual condition

Water permeable surface coating
seepage capacity, pollutant retention, drain behaviour, technical approval by DIBT

Root ingrowths in sewer systems
tree determination based on samples of ingrown roots, documentation and evaluation of damage cases, recommendation for the removal of ingrown roots and for rehabilitation of damages

Reporting and self-diagnostics ordinance
consultation for the implementation of legal specifications (EKVO, SüwVKan), documentation and optimisation of construction and flow organisation, requirement suitable update of service and operating instructions, completion and systematisation of the reporting, coordination with responsible supervisory authorities

Flow examination and comparison measurements
review of measuring devices on rain basin and sewage treatment plants, comparative measurements on site with the most modern, regularly calibrated measuring instruments, measurement of extraneous water, determination of extraneous water sources and causes

Economic viability
costs/benefit analysis for trenchless and open methods of construction, evaluation of investment and rehabilitation strategies, economic evaluation of sewer networks and its construction, measures for cost-cutting and business economic optimisation, macro economic and business economic analyses

Contact

In case you have questions about our services, we are gratefully at your disposal.

IKT - Institute for Unterground Infrastructure non-profit Institute
Exterbruch 1
D - 45886 Gelsenkirchen
Germany
Tel.: +49 (0) 209 17806 - 0
Fax: +49 (0) 209 17806 - 88
www.ikt.de
info@ikt.de

Imprint

Editor ● **IKT - Institute for Unterground Infrastructure**
non-profit Institute

Exterbruch 1
D - 45886 Gelsenkirchen
Germany

Tel.: +49 (0) 209 17806 - 0
Fax: +49 (0) 209 17806 - 88

www.ikt.de
info@ikt.de

Responsible for content ● Dipl.-Ök. Roland W. Waniek (v.i.S.d.P.)
Dipl.-Ing. (FH) Daniela Brown

Design and Layout ● taktil. Gesellschaft für Kommunikation bR
www.taktil.de
Bochum

Print ● Margreff Druck und Medien GmbH
Essen

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:

a) IKT-Association of Network Operators:
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.

You can find information on projects and services at:
www.ikt.de

IKT – Institute for Underground Infrastructure

Exterbruch 1
45886 Gelsenkirchen
Germany

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

IKT is located
ca. 30 min. off Düsseldorf
International Airport.

Published: September 2010
Circulation: 3.000 copies

Protective charge: 19,95 €