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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

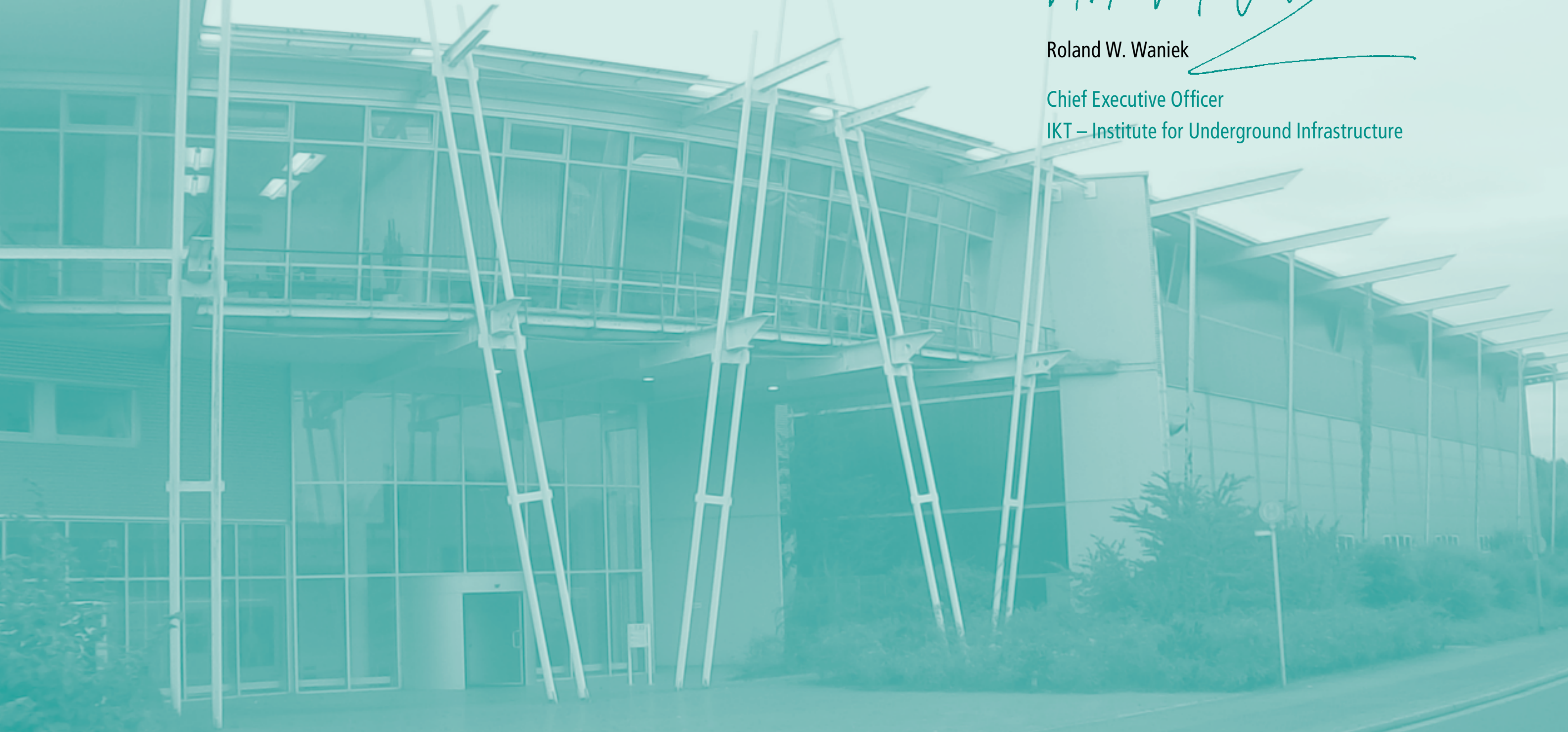
In its Product Tests, the IKT goes one step further: every comparative test is supported by a group of system operators. Decisions concerning test contents, test procedures and test evaluations are made jointly by the group in a working committee. This ensures that the tests are closely practically orientated 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 2008, 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. «

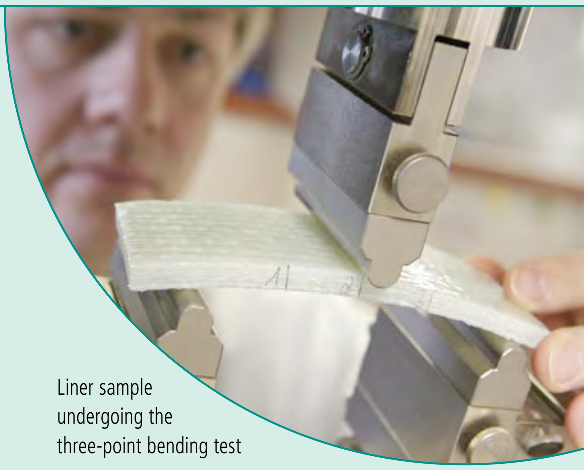
Roland W. Waniek

Chief Executive Officer
IKT – Institute for Underground Infrastructure



Content

Tube liner quality in 2007: An improvement over last year



Liner sample undergoing the three-point bending test

A pleasing trend: This year's IKT LinerReport is pleased to announce higher on-site quality levels. Test results have, on average, improved. The ongoing quality debate is starting to produce results.

The cured-in-place liner market has, for some time, been experiencing an intensive debate on quality. A good twenty-five years after the introduction of this renewal technology in Germany, discussion is livelier than ever. This is not surprising, when one remembers that tube lining has become established as the leading renovation method for waste-water conduits.

The CIPP technology competes directly with pipe replacement and has now managed to capture a highly respectable market share (around 20% of the overall market, and some 80% of the renovation market). This success story has been made possible, among other factors, by the fact that it provides customers with properties and service-lives equivalent to those of new pipes, but in most cases at lower cost.

Quality the guarantee of cost-efficiency

In the field of quality-assurance, however, CIPP liners have a built-in system disadvantage compared to factory-manufactured pipes: they are produced on-site, i.e., generally under significantly more difficult production conditions than those found in a pipe mill.

The end products are therefore submitted to strict quality testing. Random samples are taken from the cured liners and examined in the test laboratory. The reason for this: if the properties and characteristics promised are not achieved in a renewal project, achievement of the expected service-life, and thus the overall cost-effectiveness of the renewal project, becomes dubious.

Transparency

There is no doubt that the annual IKT Liner-Report, which is here presented for the fourth time, makes a significant contribution to the heated debate on quality. Its aim is to achieve clarity and transparency and to provide project clients with an objective overview of the tube liner qualities actually achieved.

The extensive liner data-base operated by the independent and neutral IKT Testing Center is evaluated for this purpose. This generates a

Table 1: Installation contractors and liner systems

Installation contractor	Liner systems	Liner type	Number of samples	IKT test ordered by	
				Installation contractor %	Project client %
ARKIL INPIPE GmbH	Berolina Liner	GRP	89	0	100
Arpe AG (Switzerland)	Brandenburger Liner	GRP	25	0	100
Brandenburger Kanalsanierungs-GmbH	Brandenburger Liner	GRP	67	10	90
Diringer & Scheidel Rohrsanierung GmbH	Saertex-Liner	GRP	71	82	18
FLEER-TECH GmbH	CityLiner	NF	46	0	100
Frisch & Faust Tiefbau GmbH	Saertex-Liner	GRP	77	0	100
Insituform Rohrsanierungs-techniken GmbH	Insituform Schlauchliner	NF	182	0	100
Jeschke Umwelttechnik GmbH	Brandenburger Liner	GRP	77	1	99
KMG Pipe Technologies GmbH	KM Inliner	NF	31	19	81
KS Kanalsanierung Friedrich e.K.	Brandenburger Liner	GRP	34	38	62
Linertec GmbH	Euroliner	GRP	39	36	64
NordiTube GmbH	UniLiner	NF	26	100	0
Rose Kanal- und Umwelttechnik	Brandenburger Liner	GRP	34	91	9
Swietelsky-Faber GmbH Kanalsanierung	Berolina Liner	GRP	73	7	93
U&W Umwelttechnik u. Wasserbau GmbH	Brandenburger Liner	GRP	73	74	26
Van der Velden Riolerings-beheer B.V. (Netherlands)	Brandenburger Liner	GRP	32	100	0
Total			**976**	**25**	**75**

GRP: Glass-fiber support material | NF: Needle-felt support material comprehensive overall picture of tube liner quality as actually achieved on project sites.

Data-base

The IKT LinerReport 2007 covers the January to December, 2007, inspection period and is based on a total of just on 1,000 on-site samples. This year, the input results have, for the first time, been obtained not only in Germany, but also from other European countries, with the application of identical test and inspection standards in all cases.

In order to avoid statistical outliers, only installation contractors for whom not less than twenty-five liner samples from five different project sites are available are included in the survey. A total of sixteen installation contractors (see Table 1) fulfilled this minimum requirement for this year's reporting period, five more than in the previous year. In the case of repeat tests, the final result obtained applies, provided the relevant tests were also performed at IKT.

Target/Actual analysis

The site samples submitted are examined at the IKT test center for two crucial properties of tube liners: stability and water-tightness. For the former, the following mechanical and geometrical characteristics data are determined, in detail:

- Modulus of elasticity (short-term flexural modulus)
- Flexural strength (short-term σ_{fb})
- Wall thickness

The data determined is compared in the context of a Target/Actual analysis against the specified minimum values. The sample is considered to pass the test provided these values are equal to or better than the target. The results are shown in aggregated form in Tables 2 to 4.

The target values for modulus of elasticity and flexural strength are based on:

a) the characteristics data from the National Technical Approval by the Deutsches Institut für Bautechnik (German Institute for Construction Technology, a government body, German abbreviation: DIBt), where the liner system has successfully passed the approval procedure or
b) site-specific minimum specifications set by the client for his specific renewal project; this data may deviate from that of the DIBt approval.

Wall thickness and water-tightness

Target values for wall thickness are defined, or are specified by the client, on the basis of stress analysis calculations. The property of water-tightness is nowadays determined in accordance with the APS test and inspection code. The result is stated either as „Tight" or „Not tight" (see Table 5 for results).

Contractual agreements

Target mechanical data and the water-tightness requirement are generally an integral component of the contractual agreement between the client and the installation contractor. More and more contracts nowadays provide precisely specified sanction mechanisms, in the form, for example, of repair or reworking obligations, or of price reductions, in case of failure to achieve target data. Great importance therefore attaches to laboratory inspection and testing of tube liners.

Overview of test and inspection criteria

Modulus of elasticity (short-term flexural modulus)

- Tube liners must be capable of withstanding loads such as those arising from groundwater, road traffic and soil pressure, for example
- The modulus of elasticity is an indicator of load-bearing capability
- If it is too low, stability may be endangered
- Test method: Three-point bending test as per DIN EN ISO 178 and DIN EN 13 566, Part 4

Results: see Table 2

Wall thickness (mean combined thickness)

- Minimum value is specified in the stress analysis calculation
- Wall thickness and modulus of elasticity jointly determine the stiffness of the liners
- Excessively low wall thickness can endanger stability
- Test method: Mean combined thickness is measured in accordance with DIN EN 13 566, Part 4, using a precision slide gauge

Results: see Table 4

Flexural strength (short-term-σ_{fb})

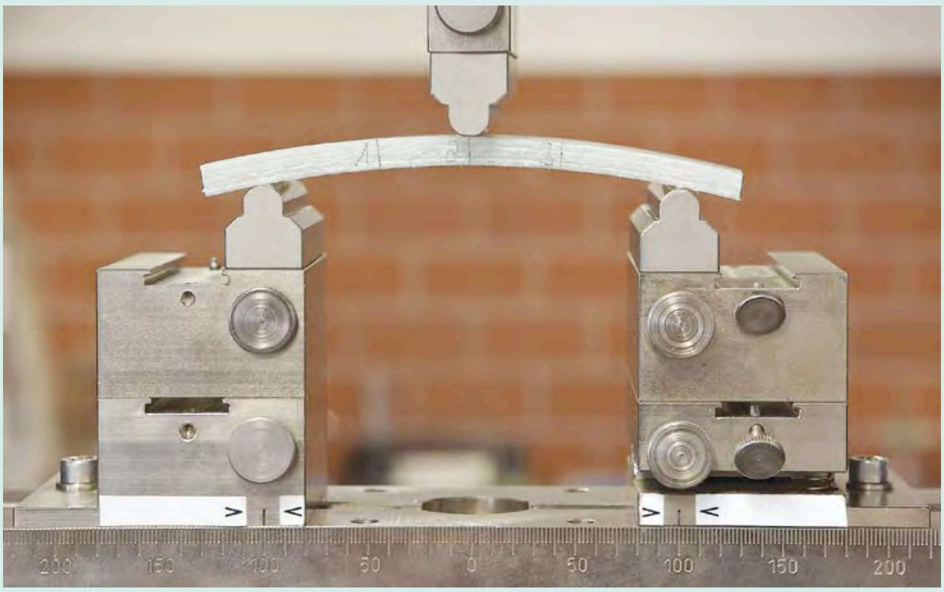
- This indicates the point at which the liner fails due to excessively high stress
- If bending strength is too low, the liner may fracture before the permissible deformation is reached
- Test method: Increase of load up to failure in the three-point bending test; as per DIN EN ISO 178 and DIN EN 13 566, Part 4 (short-term flexural strength)

Results: see Table 3

Water tightness (in accordance with APS test and inspection code)

- Cut is made into inner film and the outer film (if any) is removed
- Water containing a red dye is applied internally
- A 0.5 bar (7.25 psi) partial vacuum is applied externally
- The liner is „Not tight" if water penetrates through
- Test period: 30 min.

Results: see Table 5



Liner sample undergoing the three-point bending test

Table 2: Test results for modulus of elasticity (Short-term flexural modulus)

Installation contractor	2007			2006	Tendency
	No. of samples	Target* achieved in % of tests		Target* achieved in % of tests	
ARKIL INPIPE GmbH	66	100.0	(100.0)	99.5	↑
Arpe AG (Switzerland)	25	100.0	(96.0)	–	–
KS Kanal Sanierung Friedrich e. K.	34	100.0	(97.1)	98.8	↑
Linertec GmbH	39	100.0	(**)	100.0	↔
NordiTube GmbH	26	100.0	(100.0)	-	–
Swietelsky-Faber GmbH Kanalsanierung	73	100.0	(100.0)	89.5	↑
U&W Umwelttechnik u. Wasserbau GmbH	73	100.0	(100.0)	–	–
Van der Velden Rioleringsbeheer B.V. (NL)	32	100.0	(100.0)	–	–
Jeschke Umwelttechnik GmbH	77	98.7	(98.7)	–	–
Brandenburger Kanalsanierungs-GmbH	67	98.5	(98.5)	100.0	↓
Diringer & Scheidel Rohrsanierung GmbH	71	97.2	(94.4)	93.9	↑
Rose Kanal- und Umwelttechnik	34	97.1	(97.1)	–	–
KMG Pipe Technologies GmbH	31	96.8	(96.8)	–	–
Average		**94.1**		**89.9**	↑
Insituform Rohrsanierungstechniken GmbH	168	88.7	(88.7)	84.2	↑
Frisch & Faust Tiefbau GmbH	77	84.4	(57.1)	88.3	↓
FLEER-TECH GmbH	46	60.9	(60.9)	63.4	↓

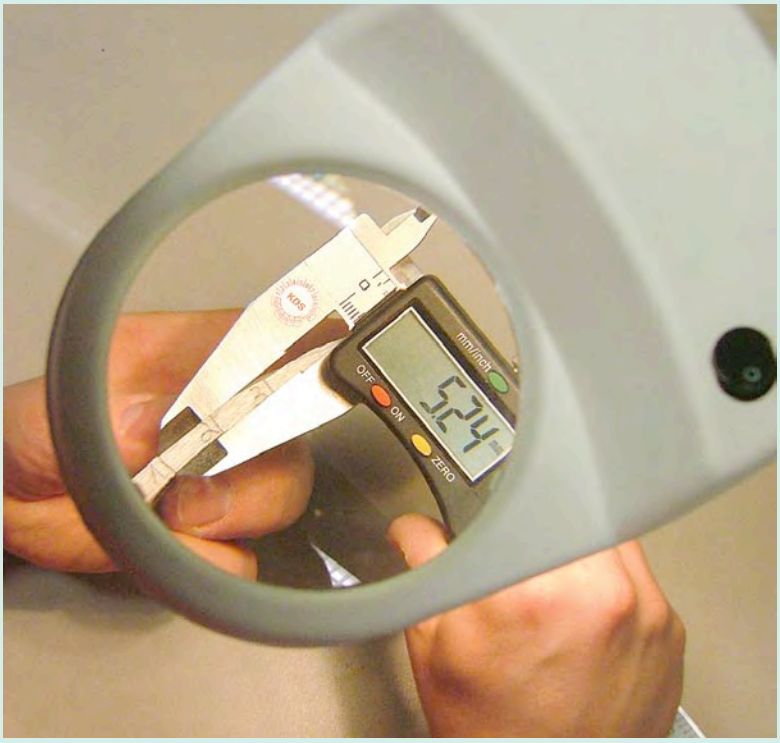
* Target data in accordance with client's information (stress analysis/sample traveller card) | ( ) Result of comparison against DIBt target | ** No DIBt approval
– Not evaluated, insufficient liner samples

Table 3: Test results for flexural strength (Short-term-σ_{fb})

Installation contractor	2007			2006	Tendency
	No. of samples	Target* achieved in % of tests		Target* achieved in % of tests	
Brandenburger Kanalsanierungs-GmbH	67	100.0	(95.5)	100.0	↔
Jeschke Umwelttechnik GmbH	77	100.0	(100.0)	–	–
Linertec GmbH	39	100.0	(**)	100.0	↔
NordiTube GmbH	26	100.0	(100.0)	–	–
Rose Kanal- und Umwelttechnik	34	100.0	(100.0)	–	–
U&W Umwelttechnik u. Wasserbau GmbH	73	100.0	(100.0)	–	–
Van der Velden Rioleringsbeheer B.V. (NL)	32	100.0	(100.0)	–	–
Diringer & Scheidel Rohrsanierung GmbH	71	97.2	(87.3)	87.9	↑
KS Kanal Sanierung Friedrich e. K.	34	97.1	(94.1)	100.0	↓
ARKIL INPIPE GmbH	66	97.0	(97.0)	92.4	↑
Swietelsky-Faber GmbH Kanalsanierung	73	95.9	(94.5)	86.1	↑
FLEER-TECH GmbH	46	95.7	(95.7)	85.4	↑
Average		**92.5**		**83.5**	↑
Arpe AG (Switzerland)	25	92.0	(92.0)	–	–
KMG Pipe Technologies GmbH	31	87.1	(87.1)	–	–
Insituform Rohrsanierungstechniken GmbH	168	78.0***	(78.0)	56.3	↑
Frisch & Faust Tiefbau GmbH	77	77.9	(32.5)	78.9	↓

* Target data in accordance with client's information (stress analysis/sample traveller card) | ( ) Result of comparison against DIBt target | ** No DIBt approval
*** DIBt approval modified with effect from June 15, 2007 DIBt; target now lower than in preceding year | – Not evaluated, insufficient liner samples

Cut made into inner film, with limitation of cut depth



Measurement of liner-wall thickness

Tightness test: liner above „Not tight", liner below „Tight"

Table 4: Test results for wall thickness (mean combined thickness in accordance with DIN EN 13 566, Part 4)

Installation contractor	2007		2006	Tendency
	No. of samples	Target* achieved in % of tests	Target* achieved in % of tests	
Frisch & Faust Tiefbau GmbH	77	100.0	100.0	↔
KMG Pipe Technologies GmbH	31	100.0	–	–
Linertec GmbH	39	100.0	97.7	↑
Jeschke Umwelttechnik GmbH	77	98.7	–	–
Insituform Rohrsanierungstechniken GmbH	175	97.1	80.8	↑
Van der Velden Rioleringsbeheer B.V. (NL)	32	96.9	–	–
Diringer & Scheidel Rohrsanierung GmbH	71	95.8	100.0	↓
Brandenburger Kanalsanierungs-GmbH	66	89.5	89.5	↔
Average		**87.8**	**82.7**	↑
FLEER-TECH GmbH	46	84.8	95.0	↓
NordiTube GmbH	26	84.6	–	–
ARKIL INPIPE GmbH	63	82.5	68.6	↑
Rose Kanal- und Umwelttechnik	34	79.4	–	–
KS Kanal Sanierung Friedrich e. K.	26	76.9	62.5	↑
U&W Umwelttechnik u. Wasserbau GmbH	73	74.0	–	–
Swietelsky-Faber GmbH Kanalsanierung	73	56.2	63.2	↓
Arpe AG (Switzerland)	25	56.0	–	–

* Target data in accordance with client's information (stress analysis/sample traveller card)

– Not evaluated, insufficient liner samples

Table 5: Test results for water-tightness (in accordance with APS test and inspection code)

Installation contractor	2007		2006	Tendency
	No. of samples	Watertight in % of tests	Watertight in % of tests	
Arpe AG (Switzerland)	25	100.0	–	–
Brandenburger Kanalsanierungs-GmbH	63	100.0	100.0	↔
Diringer & Scheidel Rohrsanierung GmbH	71	100.0	100.0	↔
Rose Kanal- und Umwelttechnik	34	100.0	–	–
Swietelsky-Faber GmbH Kanalsanierung	73	100.0	100.0	↔
U&W Umwelttechnik u. Wasserbau GmbH	73	100.0	–	–
Van der Velden Rioleringsbeheer B.V. (Netherlands)	32	100.0	–	–
ARKIL INPIPE GmbH	88	97.8	97.8	↔
Frisch & Faust Tiefbau GmbH	77	97.4	93.3	↑
Linertec GmbH	39	97.4	100.0	↓
KS Kanal Sanierung Friedrich e. K.	34	97.1	98.8	↓
NordiTube GmbH	26	96.2	–	–
Jeschke Umwelttechnik GmbH	77	94.8	–	–
Average		**93.8**	**88.8**	↑
FLEER-TECH GmbH a) in accordance with APS test and inspection code b) with reference to DIN EN 1610*	 36 10	 86.1 100.0	 61.9	 ↑
KMG Pipe Technologies GmbH a) in accordance with APS test and inspection code b) with reference to DIN EN 1610*	 24 7	 75.0 85.7	 –	 –
Insituform Rohrsanierungstechniken GmbH a) in accordance with APS test and inspection code b) with reference to DIN EN 1610* c) with reference to APS test and inspection code with lower test pressures and times in some cases**	 113 44 25	 70.8 75.0 92.0	 68.8	 ↑

– Not evaluated, insufficient liner samples | * State of the art is nowadays testing in accordance with the APS test and inspection code. Only a few clients insist on tests with reference to DIN EN 1610, which tolerates a certain amount of permeation of water through the liner wall. | ** At the request of one individual client.

Table 6: Test results classified by liner types

		Water-tightness		Modulus of elasticity		Flexural strength		Wall thickness	
Liner type	Liner system	No. of samples	Watertight** in % of tests	No. of samples	Target* achieved in % of tests	No. of samples	Target* achieved in % of tests	No. of samples	Target* achieved in % of tests
GRP	Euroliner	39	97.4	39	100.0	39	100.0	39	100.0
	Berolina Liner	161	98.8	139	100.0	139	96.4	136	68.4
	Brandenburger Liner	338	98.5	342	99.1	342	99.1	333	84.4
	Saertex-Liner	148	98.6	148	90.5	148	87.2	148	98.0
NF	Uniliner	26	96.2	26	100.0	26	100.0	26	84.6
	KM Inliner	24	75.0	31	96.8	31	87.1	31	100.0
	CityLiner	36	86.1	46	60.9	46	95.7	46	84.8
	Insituform Schlauchliner	113	70.8	168	88.7	168	78.0	175	97.1
Average			**93.8**		**94.1**		**92.5**		**87.8**

above average
below average
GRP: Glass-fiber support material
NF: Needle-felt support material

* Targets in accordance with client's data (stress analysis/sample traveller card)
** in accordance with APS test and inspection code

Table 7: Test results compared to results for previous year

Liner type	Watertight** in % of tests			Modulus of elasticity Targets* achieved in % of tests			Flexural strength Targets* achieved in % of tests			Wall thickness Targets* achieved in % of tests		
	2007	2006	+/–	2007	2006	+/–	2007	2006	+/–	2007	2006	+/–
Average												
of all samples	93.8	88.8	+5.0 ▲	94.1	89.9	+4.2 ▲	92.5	83.5	+9.0 ▲	87.8	82.7	+5.1 ▲
GRP	98.5	97.4	+1.1 ▲	97.4	95.3	+2.1 ▲	96.0	90.7	+5.3 ▲	85.1	82.2	+2.9 ▲
NF	77.4	70.1	+7.3 ▲	86.0	79.3	+6.7 ▲	84.1	69.2	+14.9 ▲	94.2	84.0	+10.2 ▲

GRP: Glass-fiber support material
NF: Needle-felt support material
* Targets in accordance with client's data (stress analysis/sample traveller card)
** in accordance with APS test and inspection code

Summary of 2007 test results

The test results obtained in 2007 produce an all-in-all more positive picture than in the preceding year. The averages for all four test criteria and for all samples rose by no less than 4 to 9 percentage points (see Table 7).

A particular leap forward was achieved by the needle-felt liner group. Their averages improved by around 7 to 15 percentage points, but remained below the overall averages for water-tightness, modulus of elasticity and bending strength. They are clearly above average only in terms of their wall thickness.

GRP liners also improved on average, whereby the increases here were significantly more modest than those for needle-felt liners, admittedly from an already higher starting level. As in previous years, wall-thickness remains the problem area, and is below the overall average.

A glance at the individual results (see Tables 2 to 5) in some cases reveals extremely divergent performances by the contractors, however. Performance was, in some cases, better, but in some cases poorer, than last year. The same also applies to the individual liner types (see Table 6).

Conclusions

The higher overall quality level of tube liners in 2007 is pleasing. It remains to be seen whether these improvements compared to 2006 constitute a sustainable trend or are merely „once-only" effects. A whole series of signals from the market does, however, indicate that the installation contractors are taking the continuing quality debate extremely seriously. Work is being invested in product and process innovations, and these companies are taking steps to tackle systematically the weak points outlined in previous IKT LinerReports.

These constructive responses by the renewal sector must be expressly welcomed and encouraged; one thing is certain: clients want tube liner technology. The coming years will feature many renewal projects, and reliable methods are needed for them. System operators have, however, become significantly more sensitive to the question of quality than in previous years, a positive result of the continuing quality debate.

Dipl.-Ök. Roland W. Waniek
Dipl.-Ing. Dieter Homann

Source: IKT-eNewsletter January 2008

1:1 simulation of pipe-jacking

side hydraulic cylinders

Pipe-jacking has proven its worth as an economically rational and environmentally safe alternative to open-cut installation of new pipelines. The pipes are subjected to exceptional loadings during the installation procedure, however, particularly in case of directional (i.e., „non-straight") pipe routes and difficult soil conditions. Test and inspection concepts applied up to now have been restricted in this context to the inspection of individual pipes and joints only, ignoring the pipe-string bed and curvature. This is the background to a research project conducted by the IKT – Institut für Unterirdische Infrastruktur (Institute for Underground Infrastructure), with financial support from the Ministry of the Environment of the German state of North Rhine-Westphalia and the Emschergenossenschaft.

A test system, using which jacking loads exerted on pipes and pipe joints, including the resultant bed stresses, can be simulated on a 1:1 scale, has been developed. The results obtained permit derivation of future recommendations for optimization of pipe joints, for planning and control of pipe-jacking operations, and for on-site instrumentational support. One prime emphasis can be found in the field of stress analysis, also with a view to model concepts of pipe loadings during jacking.

Background

Investments of around 500 million Euro annually are planned for construction of new drain and sewer systems in the German state of North Rhine-Westphalia alone [1]. A significant portion of this amount will be accounted for by the reconstruction of the Emscher system, costing approx. 150 million Euro/annum. Large sections of the Emscher drain and sewer system are to be constructed of large-diameter pipes of up to ND 2800 using pipe-jacking. This fact naturally increases even further the importance of the quality of the jacking pipes and joining methods used. The risks of potential damage, such as cracking and spalling (Figure 1), must be reduced by means of appropriate Quality Assurance provisions.

North Rhine-Westphalia's Ministry of the Environment and the Emschergenossenschaft have taken this fact as the basis for the financial support of a corresponding IKT research project [2]. At the IKT, specialists from the fields of modelling, concrete technology and geological site surveying have developed a test system using which the jacking loadings exerted on pipes and pipe joints, and also the resultant bed stresses, can be simulated on a 1:1 scale.

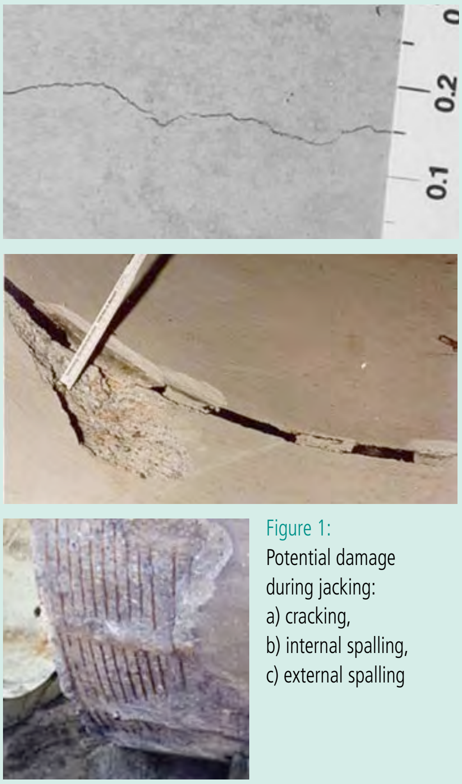


Figure 1:
Potential damage during jacking:
a) cracking,
b) internal spalling,
c) external spalling

The experimental results will permit the future derivation of recommendations for the optimization of pipe joints, the planning and control of pipe-jacking operations, and for on-site mensurational supervision and support. One particular emphasis can be found in stress analysis. The starting point for this project is provided by experience of both typical and extreme loadings obtained in various individual pipeline construction projects either currently being implemented or already completed by Emschergenossenschaft and other system operators.

The basic test procedure, process control system and mensurational equipment were firstly validated in the context of model tests on a ND 400 pipe string consisting of five concrete test objects and then scaled up to large-scale tests with a nominal diameter of ND 1600 (ext. dia. = 2100 mm, L = 16 m). The specific assignment, the test concept and the test methods are discussed, and initial results examined, in the following report.

Assignment

The idea for development of the IKT pipe-jacking simulator was conceived against the background of persistent uncertainties in the assessment of actual cases of damage and the risks of potential damage during pipe-jacking and of the broad technical discussion current at that time concerning suitable dimensioning concepts. Systematic studies into pipe-string reactions under pipe-jacking loadings were to be implemented in order to obtain knowledge and data on the performance of pipes and pipe joining methods, potentially critical jacking situations and the informational value of static modelling concepts. Figure 2 provides a comparative evaluation of the various theoretical concepts.

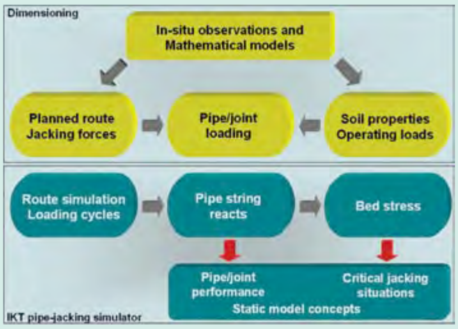


Figure 2: Comparative assessment of the dimensioning and IKT jacking-simulation task

Dimensioning

The dimensioning of pipes and pipe joints for pipe-jacking is based essentially on in-situ experience and mathematical models. Basic planning principles, project implementation methods and Quality Assurance strategies thus develop continually from the experience gained in earlier pipe-jacking projects. Model engineering concepts, generally underpinned by analytical, empirical or numerical computation methods, for their part create correlations between on-site conditions and loads and the loadings exerted on the components. These explanatory concepts then make use of the corresponding assumptions concerning local boundary conditions for the purpose of overall description of individual projects. This applies, in particular, to the selection of the planned route, the jacking forces to be applied and anticipated operating loads, and to the soil properties to be assumed, on the basis, for example, of an expert geological assessment of the site. The loadings exerted on the individual pipes and pipe joints can then be determined mathematically and used as the input data for component dimensioning. The question of whether the dimensioning models and assumptions accord with the actual situation encountered in a particular project will, ultimately, remain unanswered in cases of trouble- and damage-free jacking. Only when damage occurs do inconsistencies become apparent, necessitating the augmentation of historical in-situ observations with further experience and, where necessary, critical analysis of individual model concepts.

Concept

The concept of the pipe-jacking simulator augments the dimensioning concept of a „passive pipe", i.e., the pipe exposed to external loads is dimensioned for the reactions to loadings induced from outside, in order to obtain a further, „active" observation concept. It is known from in-situ observations of jacking operations (e.g. [3]) that the entire pipe string follows the jacking route driven by the shield in cyclical load steps. „Grinding off" of movements through curves has not been observed, with the result that the jacking route, including planned curved elements and steering corrections, can be regarded as definitive for all pipes jacked. For any given route geometry, the pipe string is subjected in every load cycle (pipe advance) to the longitudinal loading necessary for jacking. An unrestrained pipe string will react with movements perpendicular to the route during the loading cycle, depending on pipe and pipe-joint characteristics and properties and the route situation. Corresponding bed reactions will occur if these movements are completely suppressed. The concept of the pipe-jacking simulator makes use of this „active" behaviour of the pipe string under exposure to axial loading: a five-pipe string is exposed under a simulated route geometry to an axial load and the bed reactions necessary in this situation are determined. These bed reactions can then be regarded as an initial indication of the maximum possible in-situ soil reactions for given pipe and pipe-joint characteristics. 1:1 simulation using actual pipes, pressure-transmission equipment and sealing elements also takes account of geometrical imperfections (e.g. concrete surface) and non-linear elasto-visco-plastic materials properties and characteristics (e.g. wood, plastics), which are scarcely susceptible to mathematical description but which, even under subjection to major deformations and after prolonged deformation histories, are in many cases decisive.

Particular importance attaches in experimental jacking simulation to the selection of the jacking route to be simulated. It is important here, for example, to include in the simulation not only planned route elements, but also other routings permissible in-situ, such as deviations and steered curves, for example. Figure 3 shows by way of example a corresponding route which includes not only the planned straight and curved sections, but also the „Deviation from target route", „Correction" and „Return to target route" cases (see [4]).

The central aim of the research project was, therefore, the development of a test system using which the reactions of the jacking pipes, including their joint systems, could be observed during simulated jacking on a specified route and the maximum anticipated bed reactions evaluated as input data for the site geological survey and static analysis. The question of the interaction between the heading shield and the soil, and that of lubrication within the annular space thus generated, were not the subject of the study.

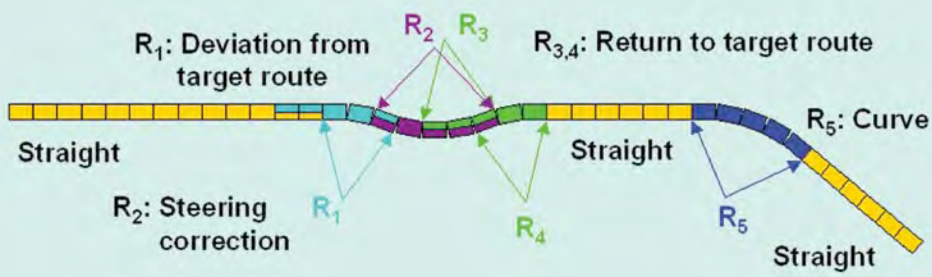


Figure 3: Route elements in the example, not to scale

The following items were also to be studied for the purpose of practical application:

- Pipe joining technology: The selection of the particular pipe-joining method has a great influence on force transmission and the sealing function of the pipe string. Particular importance attaches to the means of pressure transmission used. The influences exerted by materials characteristics and properties on the performance of the pipe string under load were to be identified and recommendations derived for selection and testing of the material.

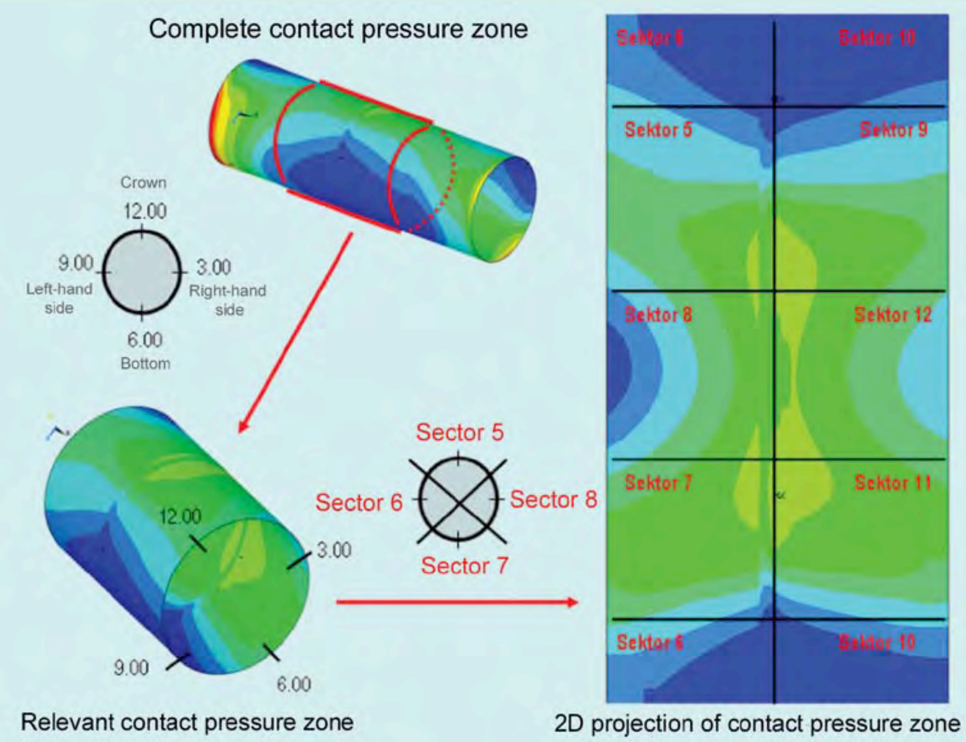
- Jacking planning and steering: Information on possible effects of steering influences and, if appropriate, recommendations on permissible tolerances, were to be derived from simulation of jacking through curves and steering movements.
- On-site mensurational supervision and support: A broad range of modern measuring systems (including pressure mapping films) was used for the first time in these tests for registration of jacking movements and loadings under 1:1 conditions. The mensurational suitability of this equipment for use under practical pipe jacking conditions was to be investigated and evaluated.

The pipe-jacking simulator

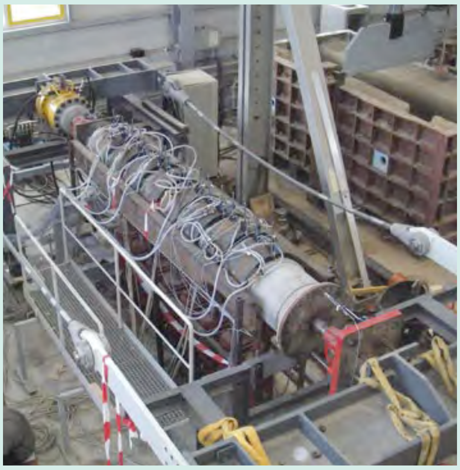
A 1:1 test system, the pipe-jacking simulator, was developed and integrated into the large-scale test facility operated by the IKT – Institute for Underground Infrastructure – in order to perform the tasks formulated above. This large-scale test facility serves during the project as an „abutment" structure for the absorption of loads and as a containment in case of unforeseen load reactions during the running-in phase. Setting-up at a different location after completion of the project is possible in principle and is, indeed, targeted.

During testing, a pipe string consisting of five reinforced-concrete jacking pipes of nominal diameter ND 1600 and equipped with the above-mentioned instrumentation, is exposed to approximately authentic jacking forces. The pipe-string and bed reactions are registered mensurationally for various pressure-transmission equipment and route situations and possible influences on the pipe-joining technology used are estimated.

The dimensioning of the test facility, including the hydraulic cushions selected for the pipeline bed, was based on geological site observations from previous projects [5] and predictive computations using the Finite Element Method (FEM) [6]. The newly developed instrumentation for performance of the tests, and the basic test sequence and procedure, were subjected to validation in model trials performed on a ND 400 pipe string consisting of five concrete test objects. The overall concept for the 1:1 scale tests (reinforced-concrete ND 1600 pipes) was completed in the spring of 2006 (Figures 4 and 5).



a) FEM computations [6]



b) ND 400 model tests

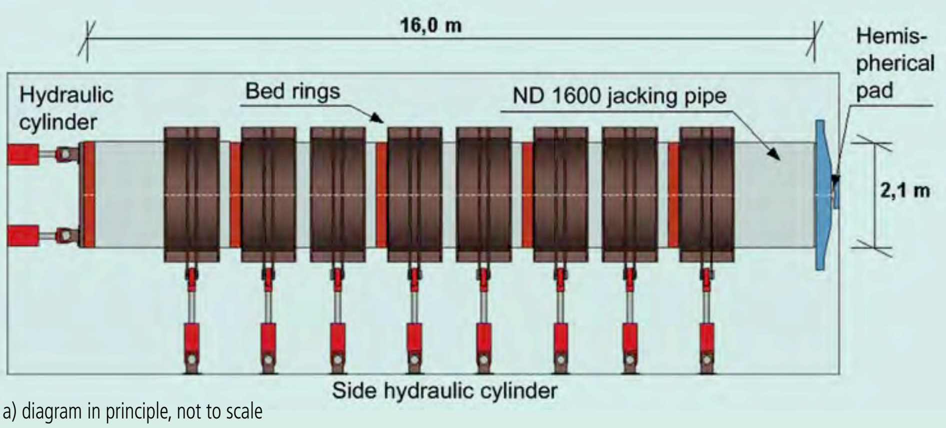
d) 1:1 jacking station (4 x 2 MN),

c) 1:1 ND 1600 (dia. = 2100 mm, L = 16.0 m) pipe string

Figure 4: Preliminary investigations and pipe-jacking simulator, scale 1:1

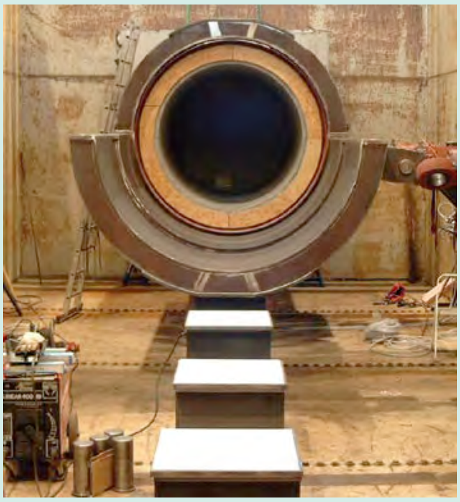
The simulator consists essentially of the following components: Jacking station, bearing stand track, pipe guide, side control unit, abutment structure, and five jacking pipes (Figure 5a).

The jacking station consists of four 2 MN hydraulic cylinders (rams) which can be addressed for both path control and force control and permit a maximum jacking force of 8 MN.



a) diagram in principle, not to scale


b) jacking station


c) bearing stand track


d) steel pipe-cushion ring

Figure 5: ND 1600 (dia. = 2.1 m) jacking simulator, force transmission and bed

This figure accords with the maximum forces needed for jacking of larger pipe lengths. Maximum force was restricted in the test, since larger forces are, even in practice, avoided by means of the use of intermediate jacking stations.

The jacking force is transmitted into the pipe string via a steel thrust ring. The connection of the hydraulic cylinders to the thrust ring is of flexible type, both horizontally and vertically (Figure 5b).

The pipes are supported by means of water-filled shell segment pressure cushions. These are positioned in the vicinity of the pipe's springline (cushion dimensions 1.2 m x 1.2 m), in particular, for mensurational registration of the bed reactions. The underside cushions serve only for support of the pipe, while the small crown cushions (Figure 5e) provide protection against unforeseen upward-thrusting loads. Two circumferential steel rings with internal diameters of 2170 mm form for each pipe the abutments for the hydraulic cushions, which are located in the 35 mm annular gap between the jacking pipe and the steel ring (Figure 5d). The steel rings are assembled from two half-shells in order to simplify installation of the jacking pipes. The lower half-shell in each case is positioned on a steel table with a PTFE („Teflon") support pad, in order that the pipes can be positioned virtually friction-free in the horizontal direction (Figure 5c). Electrical control valves on the cushion supply and return lines are used for charging and discharging of the hydraulic cushions, electronic pressure sensors for registration of pressure.

Various jacking conditions can be selected by means of horizontal positioning of the pipe guide using eight 1000 kN hydraulic cylinders. These are flexibly linked to the steel rings by means of brackets and bolts and are also connected to the side wall of the large-scale test facility (Figure 5f). The valves, position encoders and pressure sensors are used for control of the hydraulic cylinders; a specially programmed processing system permits simultaneous coordinated activation of all hydraulic cylinders.

The abutment structure consists of a steel plate reinforced on its rear side, which is supported against the rear wall of the IKT test facility by


e) shell segment pressure cushion


f) side hydraulic cylinder


g) abutment

means of two approximately hemispherical metal pads. The hemispherical pad support system permits rotation of the abutment structure about the vertical axis (Figure 5g), with the result that the „Straight", „Deviation from target route", „Correction", „Return to target route" and „Curve" route elements shown in Figure 3 can be simulated in the form of successive jacking situations as shown in Figure 6.

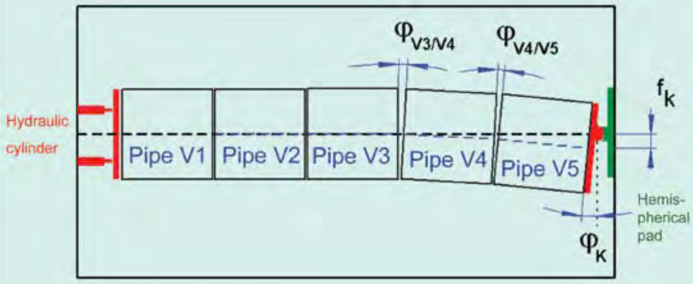
All tests are controlled, and observed in detail, using the diverse range of measuring methods and devices installed. These include inductive position encoders, rope position encoders, measuring pressure sensors, pressure mapping films and measuring strain gauges (Figure 7). The five ND 1600 reinforced-concrete jacking pipes, with a length of 3.2 m, thus themselves essentially function as instrumentation systems, and constitute a component of the overall test apparatus.

A total of 160 measuring strain gauges were applied in the form of 0°/45°/90° rosettes to the pipes for measurement of strain on the pipe circumference. Strain is recorded on the inner side of the pipes at the eighth and quarter points, and on the outer side at the eighth points of the measuring pipes (Figure 7a).

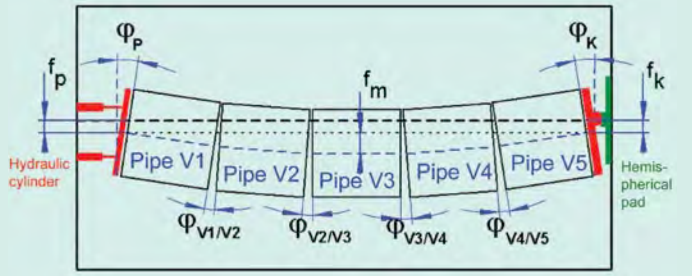
Three inductive position encoders were fitted at intervals of 120° in each pipe joint in order to record angular deflection between the pipes. The position encoders are bolted to the reduced-diameter end of the pipes and register distance from a steel bracket fixed in the mating pipe socket (Figure 7b).

Ten Tekscan film-type pressure sensors were inserted into the pressure-transmission surfaces of the central pipe in each case for measurement of contact pressure in the pipe joints. These pressure mapping films make it possible to record in qualitative terms the pressure distribution between the pressure-transmission element and the pipe socket (Figure 7c+d).

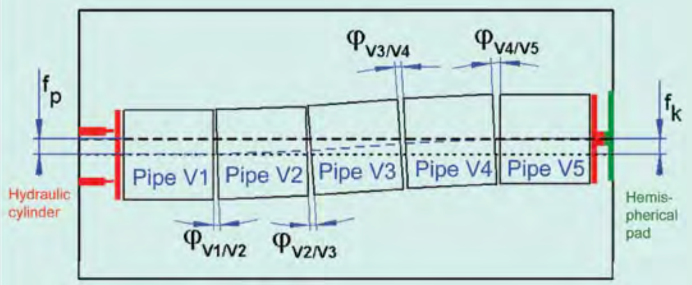
Both the hydraulic cylinders of the jacking station and those of the side steering unit are equipped with rope position encoders for steering and documentation of cylinder travel and with force sensors for adjustment and evaluation of the jacking force and possible transverse bed reactions.



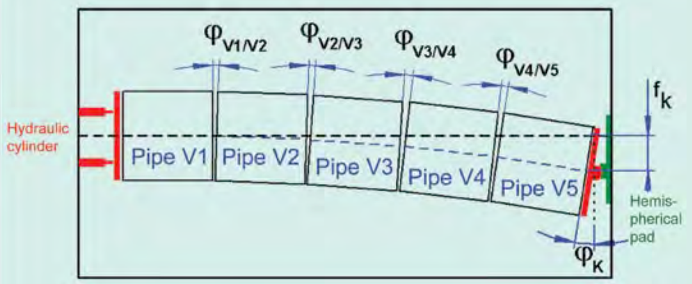
a) deviation from target route



b) correction

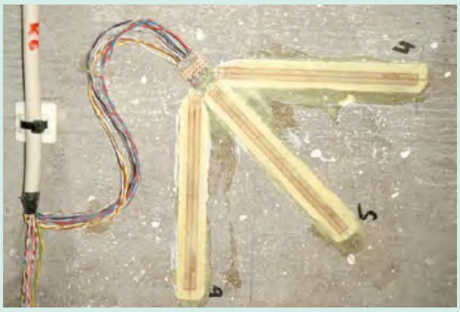


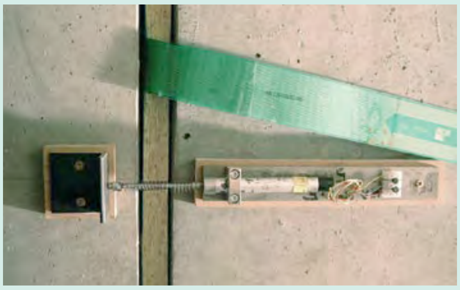
c) return to target route



d) traversing a curve

Figure 6: Jacking simulation, not to scale


a) strain gauges


b) position encoder


c) pressure measuring films


d) view into the pipe string

Figure 7: ND 1600 (dia. = 2.1 m) jacking simulator – instrumentation

Test program and initial results

The pipe-jacking simulator was used for an extensive program of tests. Comparative tests are, for example, being applied to test various pressure-transmission elements (OSB [oriented strand board] slab, natural wood, plastic) and their influence on loadings in various route configurations and critical jacking situations. Customary assumptions from static calculations are critically analyzed, as is the informational value of the mensurational systems deployed during installation operations. These tests were completed in 2007. Evaluation of results for the „Negotiation of a curve" section as shown in Figure 3 is examined below by way of example. The overall route simulation includes all of the jacking situations shown in Figure 6, with a total of 39 load cycles. In the present case, an OSB slab of a thickness of 25 mm was used as the pressure transmission element. Figure 8 shows the plot of loading and cushion pressure against test time and defines the point in time of an instantaneous analysis, the results of which are summarized in Figure 9 by way of example. The cushion pressures shown correlate to the measured, and therefore necessary, bed reactions for the jacking state set at time t_A = 1650 s.

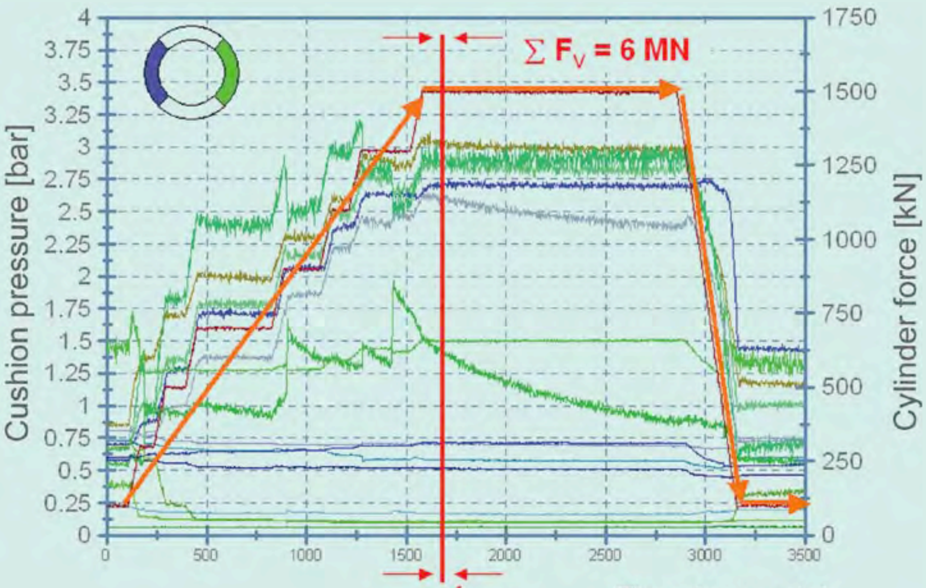


Figure 8: Plot of loadings and bed reaction across test period, time of analysis t_A

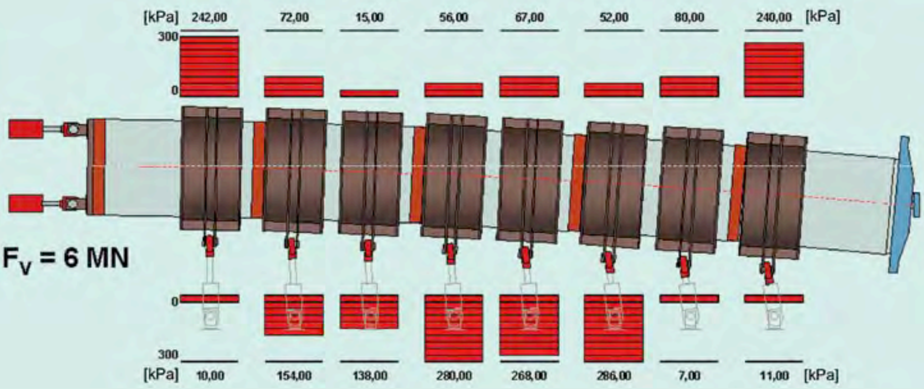


Figure 9: Specimen view of necessary bed reaction for transition through a curve at time t_A = 1650 s, not to scale

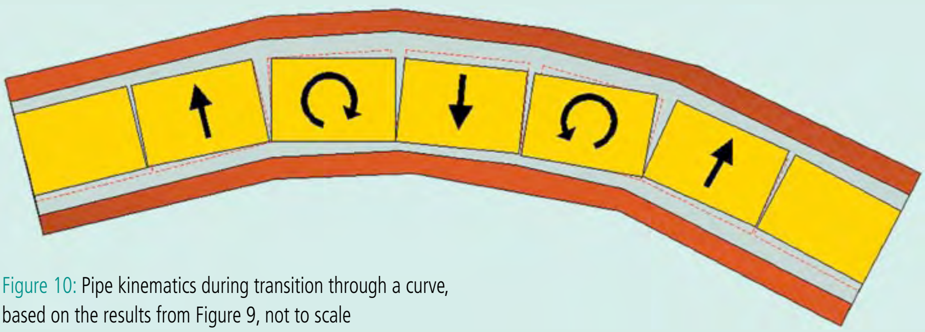


Figure 10: Pipe kinematics during transition through a curve, based on the results from Figure 9, not to scale

The pressure distribution shown in Figure 9 clearly indicates that the entire pipe curve is held against the outer side of the curve at the starting and finishing points of the curve. The pipes located within the course of the curve are subjected to a restraining and retarding bed reaction on the inner side of the curve, however. Figure 10 shows the pipe kinematics derived from this, i.e., the movements which are to be anticipated in the case of a deformable bed. The central pipes have a tendency toward a straight alignment, with the consequence that they rotate relative to the first and last pipes. As a result, it is necessary to anticipate irregular external loadings on individual pipes and corresponding transverse-force loadings in the pipe joints. These results gain even more significance as a result, in particular, of the fact that grouping of pipes to form short straight sections during negotiation of curves is also reported by experts from jacking practice. Corresponding measurements have, however, up to now been restricted only to individual cases, and the phenomena observed have generally been classified as a special case.

The measured data obtained for further jacking situations has been evaluated, tests were also conducted using different pressure-transmission elements, and the bed reactions observed has been analyzed and evaluated. Corresponding results are now available.

Conclusions

A 1:1 scale test system, using which jacking loadings on pipes and pipe joints, including the resultant bed stresses, can be reliably simulated, has been developed in the form of the pipe-jacking simulator. The initial test results permit the derivation of the following conclusions:

- As a result of the special geometrical and mechanical properties of the joining methods used, jacking pipes are extremely complex components. The pipe string is capable under jacking loads of provoking bed reactions, the magnitude of which depends on the route configuration and the selection of oversize cut.
- The negotiation of curves, in particular, must be regarded as a critical jacking state, in view of the loadings exerted on the individual pipe joints. Non-homogeneous bed reactions and corresponding transverse-force influences must be anticipated.
- Diverse loadings on the pressure-transmission element must be anticipated. Its properties will then, for their part, be capable of significantly determining the bed reactions and pipe loadings to be expected. Special importance therefore attaches, with respect to reduction of the risks of damage, to the pressure-transmission element.

Observation and evaluation of steering corrections during jacking remain of particular interest. Continued studies should, in this context, supply initial data for the more specific definition of tolerance ranges and steering strategies.

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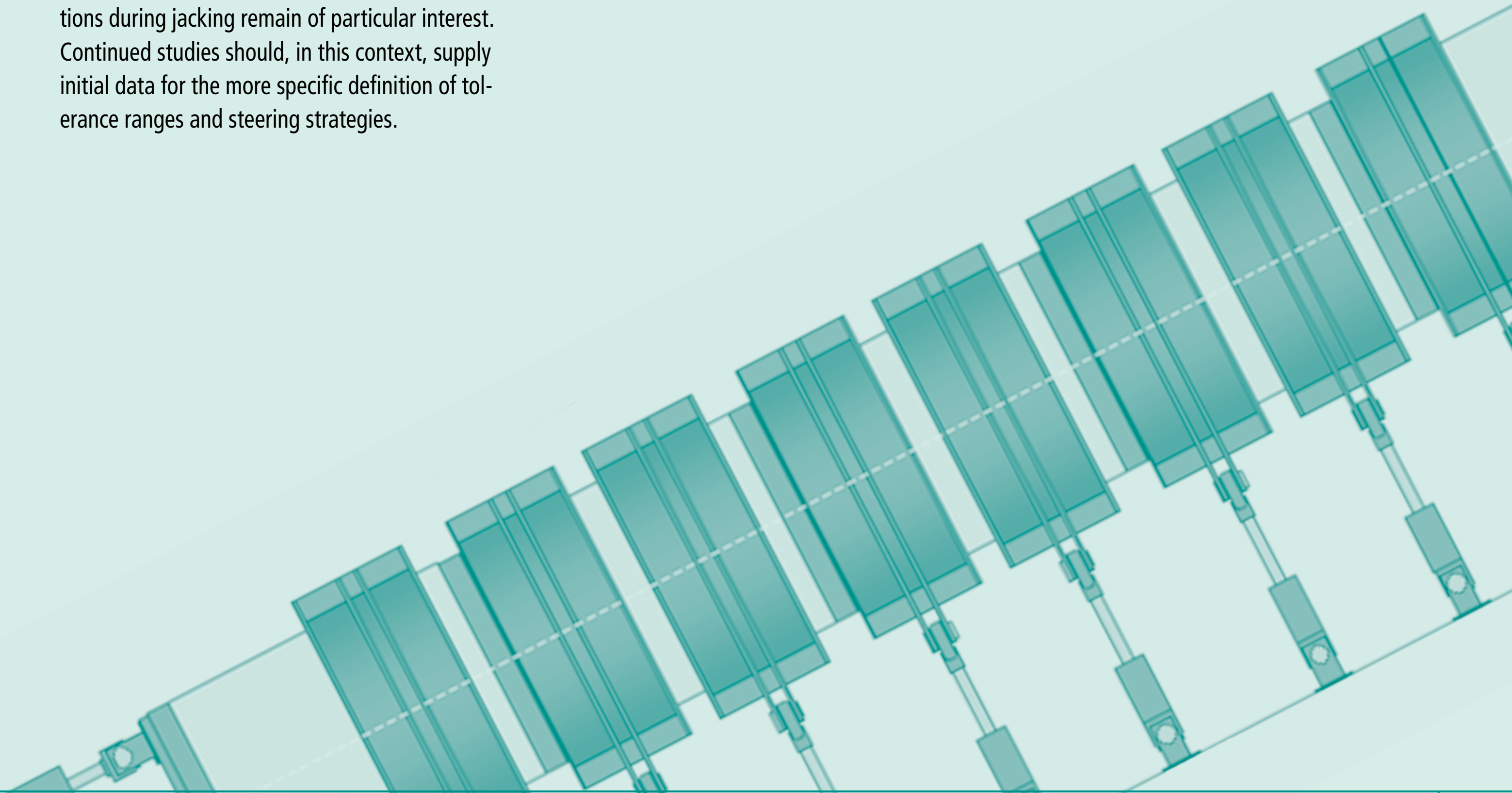
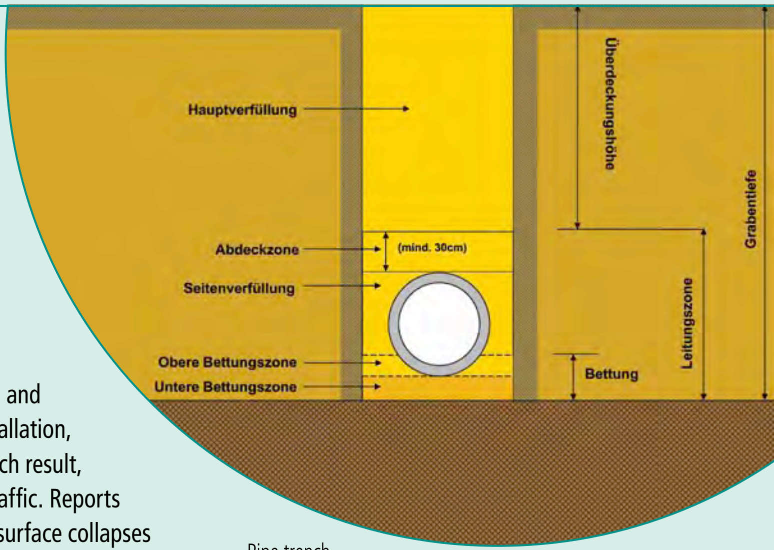


Pipe and soil are one system



Pipe trench
with reference to DIN EN 1610 [2])

How can one accurately depict the pipe/soil system and adequately analyze it? Answers to this question are provided by the IKT study „Conduit and Soil Surveying in the Non-Enterable Zone" (Kanal- und Baugrunderkundung im nicht begehbaren Bereich) [1]. This outlines the current state-of-the-art in this field, and the latest developments and research results in conduit and underground-site surveying and inspection. Particular attention is devoted to the smaller diameters.

The pipe trench as an engineering structure
Drains and sewers must be stable, correctly functioning and tight. The hydraulic functionality and the tightness of a drain or sewer section can generally be assessed simply by means of visual inspection of the interior. More detailed tightness-testing can also be easily accomplished by filling the interior of the pipe with a test fluid. Reliable information on strength and stability cannot, however, be obtained simply on the basis of pipe condition, since these factors depend on the surrounding soil and bedding conditions. The pipe trench, including the vertical closure zone formed by the highway carriageway and the hollow-cavity structure formed by the pipe should, for stress-analysis purposes, be regarded in principle as a single structure. Great importance attaches to the quantification of this overall system, i.e., the drain or sewer and the soil in which it is embedded, in cases in which strength and stability may be in doubt as a result, for example, of damage to pipes, or of subsidence or soil slips on the surface.

Examples of failures underline the possible correlation between damage to the drain or sewer system and harm to the zone surrounding the pipe, extending in some cases up to the surface. Particular attention should be devoted in this context to the age of the drain or sewer system, the construction methods and materials used for its installation, and the loads acting, which result, for example, from road traffic. Reports published in the press of surface collapses associated with damage to drains and sewers confirm this assessment. Headlines such as the following illustrate this: „Deep hole opens up in the Heimannstrasse [...] ... the carriageway had been severely undermined by a damaged drain..." [3] or „Hole appears in road following damage to drain [...] ...The drain was immediately inspected by the Civil Engineer's Department using a special camera. A length of 175 meters was found to be in extremely poor condition..." [4]. The entire „pipe-trench engineering structure", i.e., the pipe, including its bedding, overburden and the road bed, should therefore be defined as an object of study for drain and underground-site surveying, around which a detailed requirement profile for assessment of condition must be orientated. It is necessary, in this context, to differentiate the extent to which information on the following needs to be obtained:

- The pipe
- The pipe/soil system or
- The overburden soil above the pipe

Inspection targets must be defined correspondingly.

The IKT study included market research in which innovative procedures, methods and technologies for drain/sewer and underground-site inspection were recorded, submitted where appropriate to initial test deployments, and evaluated for their suitability in principle for this application.

Pipe-inspection systems

Systems for visual interior inspection are available from a large number of manufacturers. Both analog and digital camera technology, with various gear or chain-operated bearers or tractors, and both floating and submersible systems, are frequently used.

The great disadvantage of optical inspection is the fact that the detection and data-encoding of any defects is dependent on the qualification and motivation of the operating personnel and are, as a result, subjective [5].

Quantitative measuring systems can, by way of augmentation, supply further reliable data for assessment of condition on the basis, for example, of the laser light-ring projection or laser-triangulation procedures, or of mechanical methods for measurement of deformation or caliber.

Indirect physical measuring methods, such as ultrasound and geoelectrics, are at present scarcely used for inspection of pipe properties in the field of drains and sewers, and are available on the market primarily for inspection of pipelines. In these procedures, the results can be evaluated only in conjunction with other physical data, such as material density or conductivity. They are used, in general, for more extensive assessment of pipe-wall properties, such as cracks and other discontinuities, or for determination of wall thickness. It has become apparent in the context of feasibility tests that ultrasound methods may also be suitable for detection of ingrowth of tree roots into pipe joints.

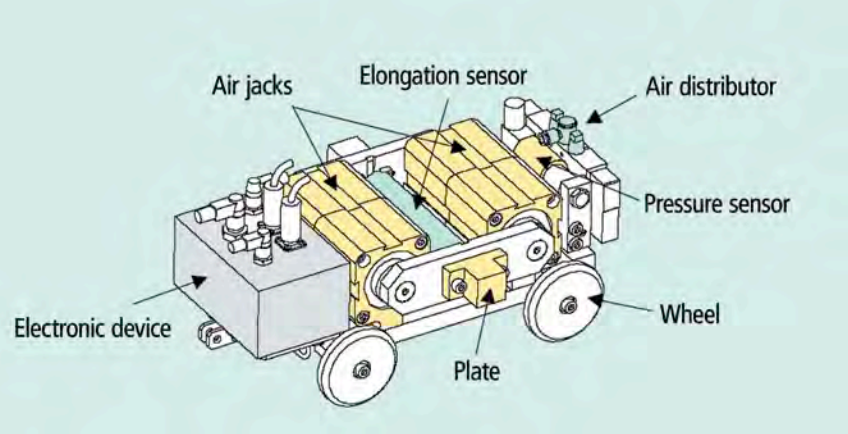
Methods for study of the pipe/soil system

Investigation of the pipe/soil system encompasses determination and recording of the static interactions between the pipe and the surrounding bedding structure. The available measuring systems expose the complete system to a pulse-type physical loading and record the system response for further analytical steps.

Camera tractor with Argus system swivel-head camera, IBAK Helmut Hunger GmbH & Co. KG, Kiel (photo: IBAK)

Camera tractor with a Type Rota-RZL rotating/ swivel-head camera, JT-elektronik GmbH, Lindau (photo: JT-elektronik)

Camera tractor with SR100 Zoom swivel/rotating camera probe, RICO GmbH, Kempten (photo: Rico)



System diagram of the „Ovameter“, after [6]

„Ovameter“ and inspection vehicle prior to use

Sewer radar system (photo: Rico)

The „Ovameter“ is a mechanical measuring method already in practical prototype use. It involves (see [6]) the application of a defined deformation and the drawing from the force measured of deductions concerning the elastic properties of the pipe/soil system, such as the horizontal bedding stiffness of the pipe zone, for example. This occurs directly during the measuring campaign and is displayed on a monitor. This measuring method can be used on flexible pipes of up to DN 600 bedded in sand or in sand/gravel mixtures. Apart from utilization for checking of compaction, the measured data supplied by the „Ovameter“ can also be used as input data for a check calculation (3D FE analysis).

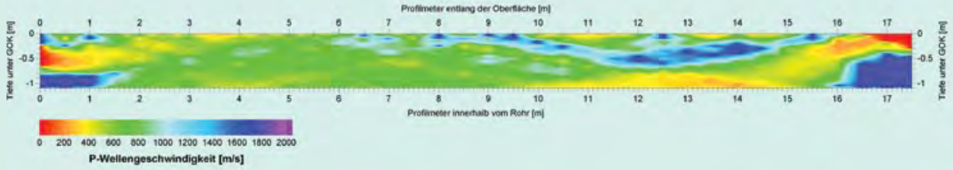
The radar method is an electromagnetic procedure in which short electromagnetic pulses are emitted from an antenna into the soil at extremely short intervals. These signals are then received again by the same instrument after being reflected from stratal boundaries or objects (cables, pipes, stones and foundations).

Measurements made in the drain or sewer can supply information - of a quality not achievable by means of measurements made from the road surface through the road formation - on the bedding and overburden conditions in the immediate surrounding area of the drain or sewer (see [7]). These areas include, in particular, bedding conditions in the gusset zone and underneath the drain or sewer. The precondition for detection of anomalies is, however, the presence of a significant change in dielectric properties (field constant, conductivity) in the zone under examination. The radar method cannot be used where groundwater is present. Instruments for practical use in the drain are already commercially available.

As a supplementary investigation method, the IKT study [1] also tested by way of example a radiometric method, also known as „computer tomography“, for detection of roots in the soil; this procedure produced good results on a laboratory scale. Considerable technical refinements and further development will, however, be necessary to permit the practical application of this system.

Use of ultrasound for detection of ingrowth of roots

Endoscopes, inserted through open fractures or drill holes in the pipe wall, for example, are also an option for the optical examination of weaknesses already detected in the pipe/soil system.



Distribution of P-wave velocity within the mathematical model (Figure: DMT GmbH)

Methods for examination of the soil structure

Seismic tomography was used for assessment of a soil structure in a test pipe length (ND 300) at the IKT site. The signals were generated in a measuring cycle using a Terfenol-D source inside the completely filled drain pipe, and were received on the surface via geophones. In a second series of measurements, the signals were generated by hammer blows on the site surface and were received by hydrophones inside the completely filled conduit.

Graphic depiction of the velocity distribution of the P waves was the result obtained from the „hammer-blow measurement“. No larger intervening objects or significant changes in soil structure are apparent here. Only water-saturated zones of the soil structure and densely compacted soil material are visible (blue zones). Evaluation of the data obtained in this way makes special demands on operator qualifications, but the data, once evaluated, can also be used by the „mensurational layman“ as the basis for further civil-engineering assessment.

In addition to the use of radar from the drain, as described above, the radar method is also used, and is being further developed, as a measuring system for deployment from the road surface. The radar procedure was also used in the IKT test length for assessment of the soil structure. It is possible – above the groundwater table – to obtain measured data suitable for evaluation.

Conclusions and perspectives

The study examined provides an overview of the current state of drain and underground-site inspection technology and of the products under research development or already available on the market. Particular attention is devoted to the requirement-profile for assessment of

condition in drains of small, non-enterable diameters. Present-day condition assessment and evaluation practice demonstrates that:

Optical inspection itself already fulfils in principle the requirements of the technical rules for assessment of condition. Digital systems with supplementary evaluation software (2D and 3D projections), which assist resolution of the individual inspection and evaluation stages, are also coming into increasing use. Inspection systems employing laser technology, for example, may augment the qualitative image with further measured data.

Information obtained solely from optical inspection is rarely sufficient for reliable **assessment of strength and stability** (collapse, for example). In addition to information on the pipe, a stability analysis - including that required with reference to applicable codes for stress-analysis calculation – necessitates more extensive knowledge of the pipe/soil system in the pipe zone and the overlying soil. Damage patterns in drains document this necessity extremely well.


Geophones for signal reception on the site surface


Terfenol-D source for signal generation in the completely filled conduit


Signal generation on the site surface, using a hammer


Series of hydrophones for reception of signal in the completely filled conduit

Devotion of greater attention to the underground site during inspections is also targeted via an **augmentation of the procedural rules** by the DWA (German Association for Water, Wastewater and Waste) since, in particular, geophysical procedures, for example, are still frequently received with skepticism by practitioners. The reason for this seems to be that the use of this technology necessitates special qualifications and that it is also scarcely possible to make interpretation of the results comprehensible for the layman.

A large range of tractors, robots and remote-controlled manipulators can also be used as carrier systems for new inspection technologies; these are, indeed, already available for inspection of pipes and other conduits, and for use underwater and in poorly accessible or impassable terrain.

More complex inspection and measuring systems have already been used in numerous research projects, and also, in individual cases, in practical applications. A trend is observable in the field of optical inspection and surveying systems, in particular:
Laser-based measuring instruments, mechanical test systems (the „Ovameter“) and radar are in use even today as **supplementary inspection methods** for acquisition of pipe geometry and pipe/soil properties. A number of measuring modules are also available for augmentation of classical video inspection systems, such as the laser light-ring method for measurement of cross-section.

Ultrasound for analysis of the pipe wall and of welds can be considered standard practice, particularly in the field of pipelines (i.e., metal pipes).

High-tech measuring systems have in the past generally been developed in cooperation with universities and research corporations, with considerable public financial support in many cases. The target here has frequently been that of combining a large number of different technologies in multi-sensor systems in such a way that even complex problems can be solved using a single tractor. Scientific analysis has focused in this context on the potentials and limitations in principle of these methods for practical use. This has generally taken the form of pre-competitive research, and practical testing up to marketing maturity in many cases remains to be performed.

Individual **geophysical measuring methods**, and radar, in particular, have also already been used in non-enterable waste-water conduits. Other geophysical methods, such as seismic tomography, for example, appear to be suitable in principle, but still require significant levels of development input to reach practical maturity. This would involve, for example, the movement and precise positioning of the sensors within the waste-water conduit, the identification of suitable sonic sources for on-site use, and the delineation of potential interference factors, such as ambient noise and vibration, for example.

In many cases, the simultaneous use of different measuring procedures is necessary to achieve comprehensive analysis of the pipe/soil system. In addition, calibration against results obtained from classical underground-site surveying, using exploratory excavations, bore holes or probe penetration tests, for example, is always advisable. The qualitative and dispersed information from inspection using geophysical methods can thus be calibrated and checked for plausibility on the basis of quantitative measured data obtained from specific individual points.

The following needs for information and study can be ascertained with a view to the future use of innovative measuring methods for conduit and underground-site surveying:

The currently customary assessment of condition on the basis only of optical inspection of the interior is not sufficient. In addition to the „cavity structure“, the „pipe-trench engineering structure“, through the drain pipe, also extends to the surrounding soil, the overburden and the road bed and surface. Any further development of the procedural rules should take this as its starting point and also incorporate the correlations illustrated in the stress-analysis calculation into operating knowledge. This would make it possible to derive practical recommendations orientated around the operating personnel's special needs for information. It would then be possible, in addition to the already known damage patterns, to obtain supplementary information on the pipe environment, such as traffic loads, nearby construction activities and lines, the condition of the carriageway deck, and the groundwater table, for example.

The diverse range of possible surveying methods necessitates knowledge of specific potentials for and limitations on their use. Any decision on which of the many inspection methods can be rationally deployed on economic criteria will depend, in particular, on local boundary conditions, and will remain an engineering decision. Correlations between recognizable damage patterns, local loading conditions and possible support defects and cavities must be recognized and rational **decision criteria for selection of methods and technologies** developed on the basis of laboratory investigations and test deployments in waste-water conduits. The individual measuring systems must, in particular, be evaluated in terms of their resolvable information density and their accuracy.

A present-day market survey indicates that **modular measuring systems**, which can then be used in combination for solution of diverse problems, will be developed **to an increasing extent** in the future. Specialized suppliers (optical inspection, measurement, surveying of the pipe environment) can provide specialized services under a joint qualification arrangement. The tendering, supervision and documentation procedures for such services have largely not yet been defined. It may be necessary here to draft corresponding **tendering recommendations** for piping system operators.

It remains to be noted, as a concluding observation:

Despite the rapid progress of technical developments, **conduit and underground-site inspection** of an entire system would appear to be scarcely economically feasible. Innovative technologies are at all times in competition with tried and proven underground-site inspection methods. New technologies will be able to become established at all only once it is possible to anticipate improved information at no additional cost, or other economic benefits. Their utilization therefore appears to be restricted, at least for the present, to individual cases, such as pipe failures that present a particularly high potential hazard.

Genuine prospects are possessed by the so-called **„transparent conduit“**, if the requirements for inspection of the „pipe-trench engineering structure“ are taken into account in the planning and dimensioning of new systems, in the selection of pipe and soil materials, and in quality assurance during installation. Corresponding correlations must be recognized in future studies and research activities, and further elaborated in product-life-cycle analyses.

Results on the Internet

This report presents only a selection of the results of the „Conduit and Soil Surveying in the Non-Enterable Zone“ study. Both the complete and the abbreviated versions can be downloaded from the Internet at: www.ikt.de

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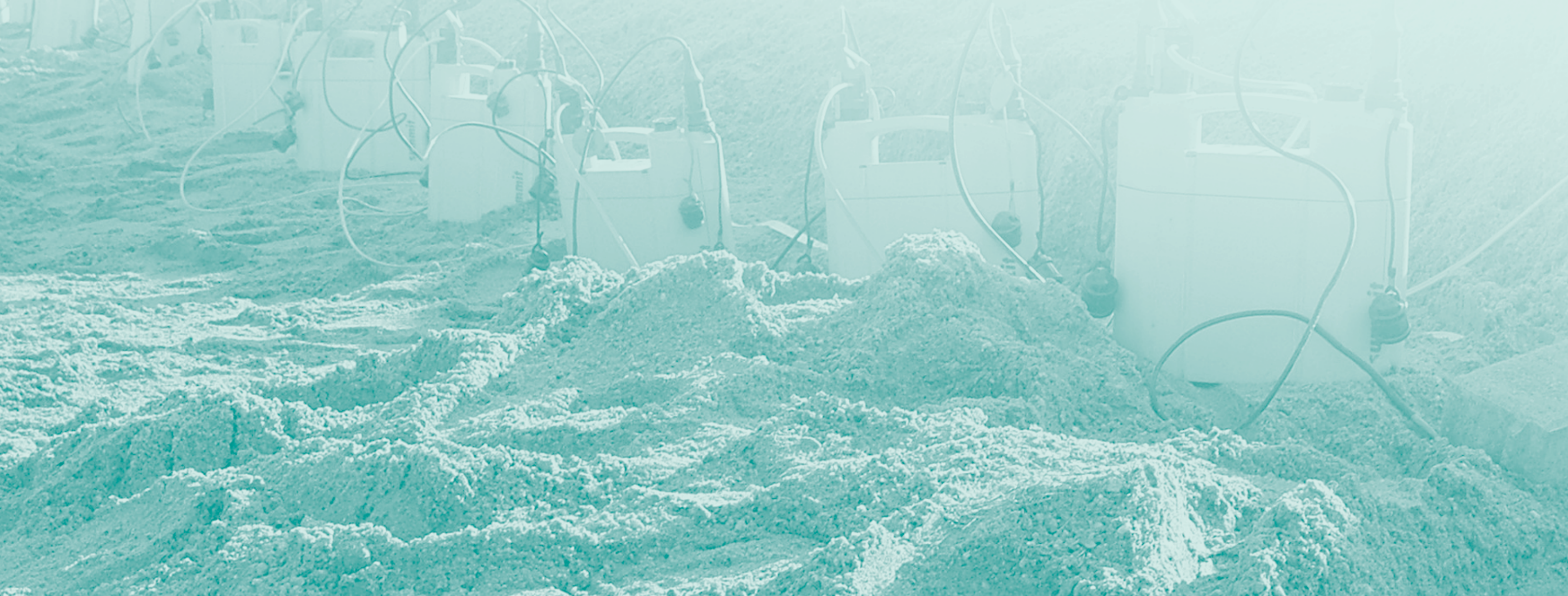
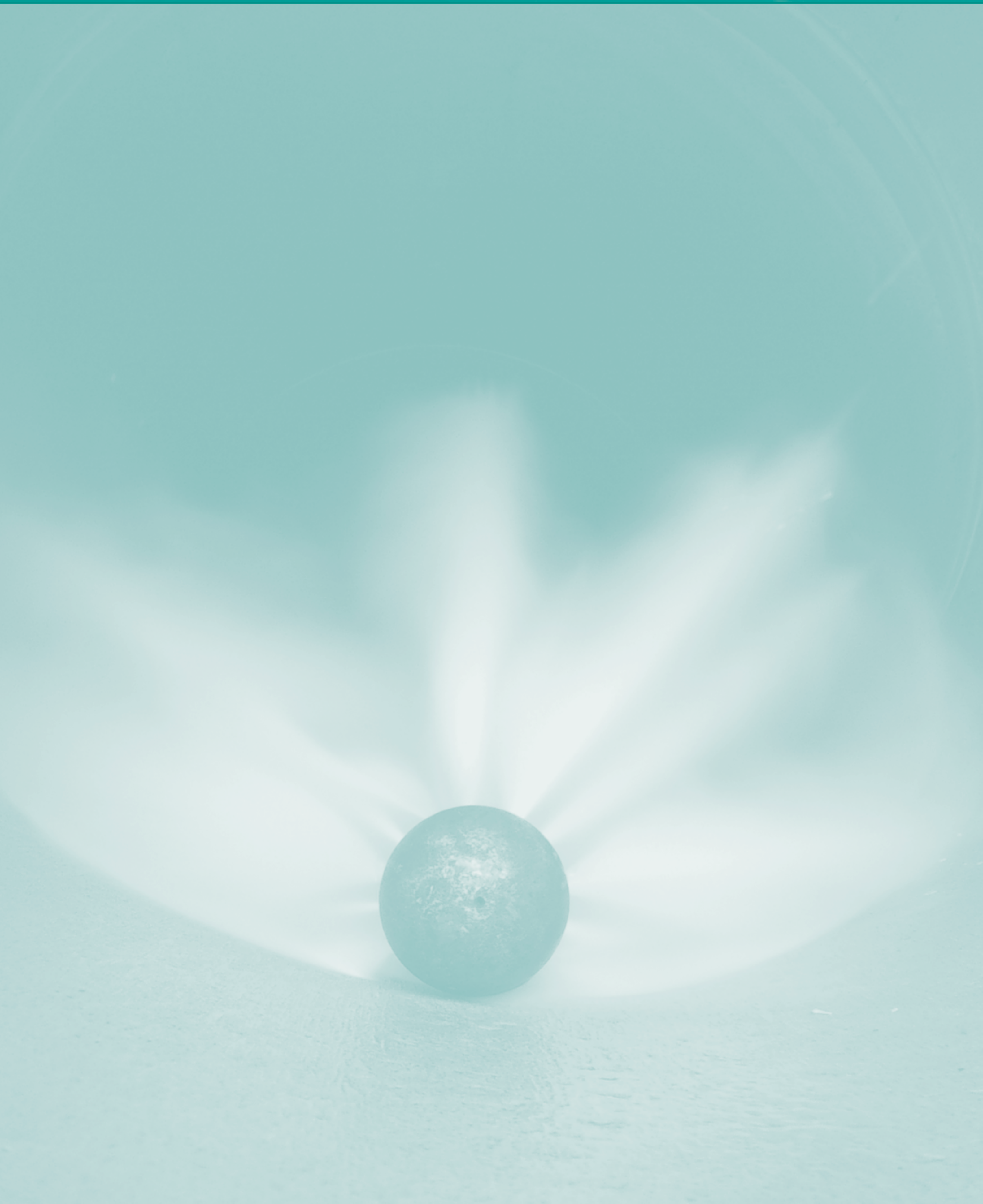
Source: IKT-eNewsletter October 2007





Inspection of partially filled conduits

Various inspection methods

Many system operators are confronted in the case of partially filled conduits with the question of „How do we inspect it?“. In the context of a pilot project, the IKT and the *Stadtentwässerungsbetrieb Paderborn* (Paderborn Municipal Drainage Corporation; German abbreviation: StEB) have examined a range of different inspection options. The results have now been published.

Determination of system condition

Existing regulations, such as the *Selbstüberwachungsverordnung Kanal* (Self-monitoring Ordinance for Drain and Sewer System Operators, German abbreviation: SüwV Kan) applicable in the German state of North Rhine-Westphalia (NRW), oblige system operators to survey and determine the condition of their entire conduit system at regular intervals. Many operators have not insignificant doubts in the case of partially filled main drains, in particular, for which reason numerous operators have not yet established the condition of these conduits (see [1]).

Due to a lack of suitable strategies and methods, the StEB had not inspected its main sewer since its commissioning in 1981. The company therefore initiated, jointly with the IKT, the „Inspection of partially filled conduits“ pilot project [2]. The concluding report, containing detailed results, is available for download from the Internet: www.ikt.de

Practical deployments and IKT test sections

A number of solution variants for optical inspection of a 5.7 km long part-section of the Paderborn main sewer (total length: 8 km) were to be drafted and implemented.

IKT monitored and documented ten practical deployments in Paderborn. The knowledge gained was evaluated in terms of advantages and disadvantages, in order to determine any available margins for improvement, and the potentials and limitations for practical use of the various techniques tested. The results will make it possible to provide conduit-system operators with orientational data for the preparation of the planning of future systems in a manner permitting accurate inspection.

Tests in IKT test sections

Tests were performed in partially filled IKT test sections in order to examine under repeatable boundary conditions methods of lowering the water level and inspecting the bottom area of the pipe interior. Two techniques, in particular, were used:

- An ejector, to lower the water level and
- A pressure chamber for optical inspection of the bottom of the pipe interior

Ejector: an ejector (Figure 1) did, indeed, make it possible to significantly lower the water level, but not to keep the bottom of the pipe interior completely free of water. In addition, the water-spray and formation of aerosol observed during performance of these tests can also have a negative effect on the quality of any optical inspection performed in parallel.

Pressure chamber: a pressure chamber open at the bottom (Figure 2, next page) was set up in the IKT experimental section, which was flooded with simulated waste-water. This water was expelled, in one case, by air (Variant A) and, in the other case, with clear fresh water (Variant B).

In Variant A, the level of the simulated waste-water in the pressure chamber was, indeed, lowered significantly, but not completely. Optical inspection of the bottom of the pipe appears to be at least partially feasible using Variant A. Potentials for improvement do, however, remain, with respect to the lowering of the water level and the avoidance of water spray.

Figure 1: Use of a large-section ejector nozzle in the IKT test conduit section; Left: Lowering of the water level from 20 to 12 cm; Right: Turbulence and water-spray behind the nozzle, height: approx. 60 cm

Figure 2: Elements and dimensions of pressure chamber
Top left: Individual elements: side-walls, top;
Top right: Overall view along the pipe
Bottom: Side-wall with compressed-air connection;

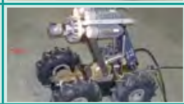
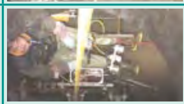
	Inspection method		On-site deploy-ments	Range [m]	Water level [cm]*
I	Mobile Robot A: Argus 4[1] with chassis[2] for large-caliber pipes, photo: IKT		3	1.994	20 to 25
II	Mobile Robot B: Argus 4[1] with tractor mounting[1], photo: IKT		2	474	20 to 30
III	Mobile Robot C: Tractor P448[3], photo: IKT		1	(84)	30
IV	Floating robot: Argus 4[1] with float[4], photo: IKT		2	724	20 to 25
V	Manned-vehicle access: Tractor[5] and Cerberus hand-held camera[1], photo: IKT		2	1.208	10 to 20
VI	Human access to conduit: Equipment supplied by ISAS GmbH, Füssen/Germany, photo: IKT		1	824	25 to 30
	*after water management provisions; normal partial filling in operational condition approx. 90 cm			∑ 5.224 (92 % of total length)	

Figure 3: Overview of inspection deployments at the Paderborn site

[1] Manufacturer: IBAK Helmut Hunger GmbH & Co. KG, Kiel (Germany)
[2] Manufacturer: Pader Kanal Technik - Rohr Frei GmbH & Co. KG, Paderborn-Sennelager (Germany)
[3] Manufacturer: Radiodetection Ltd., Bristol (United Kingdom)
[4] Manufacturer: Lönne Entsorgung GmbH & Co. KG, Lippstadt (Germany)
[5] Manufacturer: Tauchunternehmen und Apparatebau Hirt, Koblenz (Germany)

Implementation of Variant B indicated that the simulated waste-water could not be adequately expelled from the pressure chamber using fresh water obtained directly from the potable-water main. Inspection of the bottom of the pipe was therefore not possible.

In-situ inspections in Paderborn

A detailed „Actual" survey was performed prior to the inspections. This procedure consisted of a number of operations; these are described in detail in both the complete and the abbreviated version of the report (available for download at: www.ikt.de).

The project team took the Actual situation as the basis for the development of conceptual solutions and solution-variants on the topic of conduit cleaning, water control and inspection. Those procedures which, under the given boundary conditions, appeared suitable for on-site use, were then selected.

The water management concept comprised the following operations:

- Shutting-off of a feeder into the main sewer and temporary storage of the waste-water
- Performance of the inspections in the low-influx nighttime hours between 0.00 h and 6.00 h
- Agreement of inspection dates with local industrial enterprises (which also discharge water during the night)

Six different inspection methods were used at Paderborn; these took the form of three mobile robot systems, similar to those also used for inspection of non-accessible (i.e., non-walk-in) conduits, a floating robot system and, in each case, a technical solution for manned-vehicle access and for human access to the conduit. Figure 3 shows for each inspection method the number of deployments, the length of the conduit section examined, and the water level during the inspection period.

The colour-coded markings in Figure 4 show the various sections inspected within the overall 5.7 km long sub-section. The two black zones (of lengths of 154 m and 322 m, respectively) could not be inspected, since it was not possible to access the manhole shafts as a result of local boundary conditions. The result of monitoring of practical deployments at Paderborn was the obtainment of the following insights concerning the potential usefulness and limitations of the systems deployed under the given boundary conditions.

Floating robots

The use of floating robot is a possible option in cases in which the conduit to be inspected is relatively full at all times and the implementation of suitable water-management provisions would cause disproportionately high costs referred to expenditure for pure determination of condition. In addition, provided the water is sufficiently deep, depositions in the bottom area of the pipe interior do not obstruct this system.

Only a rough inspection is possible with this system, however, since the camera permits only visual inspection (i.e., via optical instruments) of the gas space. In addition, it must also be noted that a puller system (e.g. a winch) and a traction

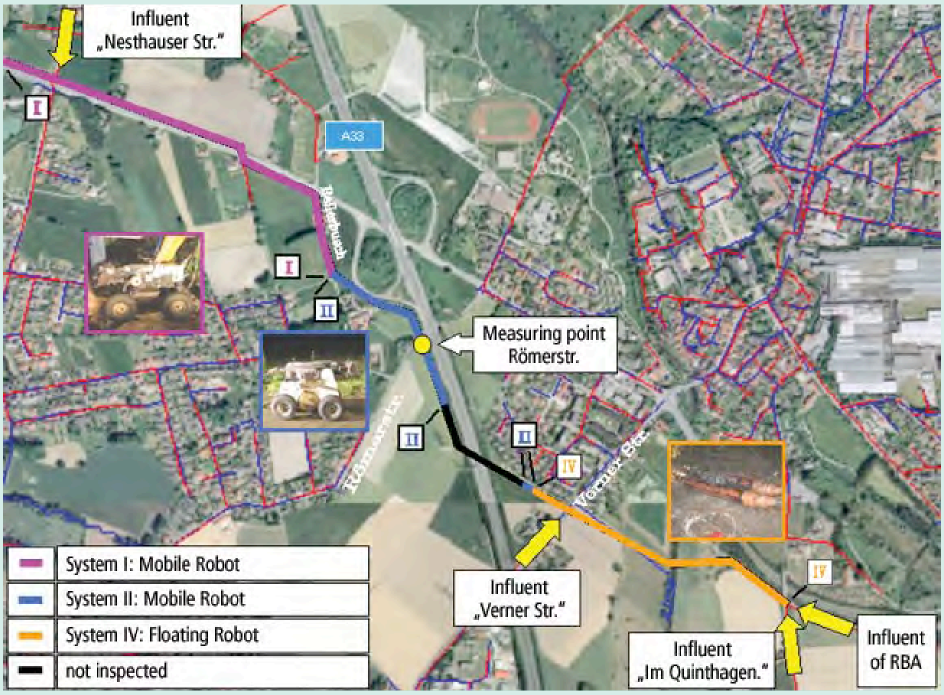


Figure 4a: Eastern section of the system inspected, inspection methods used

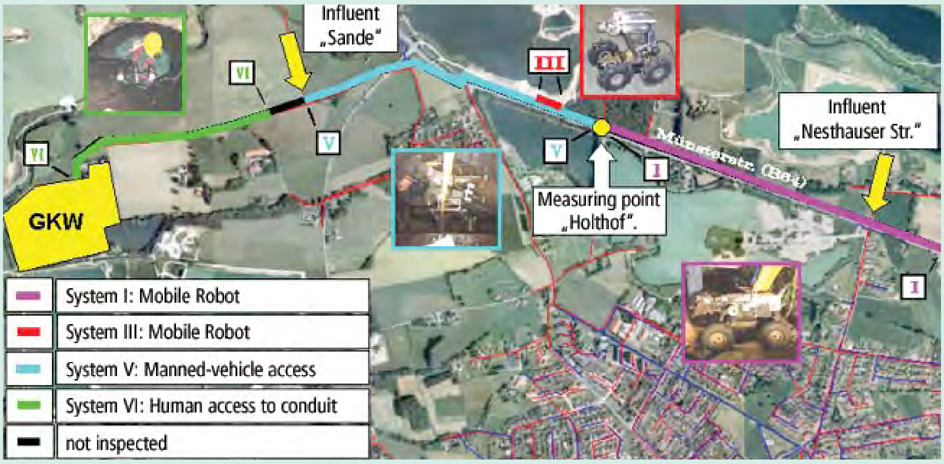


Figure 4b: Western section of the system inspected, inspection methods used

rope are necessary for propulsion of this inspection system. The passing of the rope through the conduit, in particular, can be time-consuming.

Figure 5: Argus 4 floating TV inspection robot (manufacturer: IBAK Helmut Hunger GmbH u. Co. KG), showing float (manufacturer: Lönne Entsorgung GmbH u. Co. KG)

Limitations on the use of this inspection method may result from waste-water turbulence, since this can result in the recording of blurred and therefore unusable video data.

Unmanned mobile inspection

Elevated flow of waste-water, and depositions or drain obstructions, can result in aborting of condition-inspection where unmanned mobile inspection systems are used. In addition, the water level also has an influence on the scope of the inspection, since, on these robots, too, the only sensor takes the form of a camera, using which the gas space can be „visually" (i.e., optically) inspected. Against this background, low

Figure 6: Argus 4 unmanned mobile TV inspection robot (manufacturer: IBAK Helmut Hunger GmbH u. Co. KG), with chassis (manufacturer: Pader Kanal Technik – Rohr Frei GmbH u. Co. KG)

water levels and the elimination of depositions are, therefore, the precondition for successful use of mobile inspection devices. The time required for insertion of such robots into the conduit and for their removal from it is generally short, since these machines can in most cases be passed in operating condition through standard manhole openings. Greater work input can, however, occur if, for example, step irons in the manhole shafts hinder robot access, and the robot therefore has to be assembled in the shaft. The mobile inspection systems used supplied a steady video image. It was found that changes in direction in the conduit, which occurred with angles of up to 60° during the practical tests, can be safely negotiated even by non-steerable robots.

Structural details, such as side infeeds and pipe joints, were recorded by pivoting the camera and using the zoom function. It was necessary to utilize these functions throughout the inspection, however, in order to permit detailed examination of the conduit as a whole. It is to be expected that this would significantly increase the times required for inspections.

Access

It became apparent that, unlike the situation with unmanned inspection methods, the use of manned-vehicle and purely human access permitted more detailed inspection of conduit condition. Unlike camera-robots, humans perceive their environment in 3D and are capable of using their sense of touch and performing manual activities. These abilities made it possible during the manned in-conduit deployments in the Paderborn system to register even minor damage, to examine abnormalities of the conduit cross-section located in the gas space by means of tactile investigation, and to take material specimens from the conduit structure. In addition, the inspector was also able to investigate the part of the conduit located below the water level with his feet, in order to inspect it for any significant damage or depositions.

Figure 7: Conduit entry: ISAS GmbH inspector

It is necessary, alongside the above-mentioned advantages of manned inspection methods over unmanned procedures, to take account in their use of two important factors: on the one hand, persons working in such conduits are exposed to a number of hazards; emergencies can, for example, arise as a result of toxic and/or explosive gases. Suitable safety precautions, such as ventilation of the conduit, the use of gas-warning analyzers, and the wearing of self-rescuer equipment or breathing apparatus, are necessary in order to minimize such dangers. On the other hand, the hand-held cameras used can result, depending on local boundary conditions and the expertise of the inspector, in unsteady or blurred video images. The performance of test deployments in the system to be inspected is recommendable, to permit assessment of such factors in advance.

Manned-vehicle access

In the case of manned-vehicle access, the inspector sits on a tractor, which is drawn through the conduit and is designed in such a way that its wheels run along the inner surface of the pipe above the waste-water level. This results in specific advantages compared to purely human access to the conduit: there is no danger of falls and the tractor provides the inspector with a support. Inspection of conduit condition can be performed at higher water levels and flow velocities, with no disturbance from depositions on the bottom of the pipe interior.

Purely human access, on the other hand, necessitates significantly shorter preparation times, since neither the assembly of a tractor nor the installation of a puller system and a traction rope are necessary. Where water levels and flow rates are low, and there are few depositions, human access is the better option for detailed inspections.

Planning recommendations: Inspection

Figure 8: Manned-vehicle conduit access: inspector with tractor (manufacturer: Tauchunternehmen und Apparatebau Hirt)

The drafting of a universal model service specification for inspection of partially filled conduits appeared not to be a rational option, due to the diverse requirements for inspection of partially filled conduits, resulting, for example, from nominal diameter, section length, waste-water flow and water level. It appeared instead to be more rational to provide the responsible engineer with general notes and indications for the preparation of inspection projects and for inspection-orientated planning and design of future systems. The scope of functions includes in this context not only the selection of a suitable inspection system or procedure, but also the preparation of supplementary provisions for support of the inspection operation, such as water management or conduit cleaning, for example.

a) Actual survey

The precondition for planning is detailed knowledge of the object or system to be inspected. For this reason, the performance of a survey of Actual condition is recommended as an initial step. Examination of existing documentation, walking of the conduit route on the surface, and interviews with the drain/sewer-system operator, are all potential methods for the obtainment of the necessary information.

b) Development of solution-variants

Solution-variants for implementation of the inspection project can be developed on the basis of the survey of Actual condition in the second planning stage. In order to lower water levels for the period of the condition-inspection, a check should be made to determine the extent to which chronological fluctuations in flow rate can be exploited, or temporary storage potentials for the backed-up waste-water implemented using pumping stations or valves. Where these options are not possible, other temporary water-management provisions must be considered, such as the use of siphons and/or mobile pumps and shut-off elements. The accessibility of the conduit will depend on the topography, and on the surfacing and utilization of the surrounding land. The insertion into the conduit of inspection equipment, pumps and shut-off elements may be facilitated (but may, of course, also be restricted) by the dimensions of the manhole opening and geometry, and the condition of the manhole-shaft structure (size and arrangement of walking surfaces, the dimensions of the working chamber and the safe condition - or otherwise - of the step irons).

c) Method selection

In the third planning stage, i.e., selection of the most appropriate method, the solution variants developed should be examined not only from the viewpoint of basic technical feasibility. It is also necessary to determine, on the one hand, the extent to which the content and qualitative requirements specified by the client, such as the following, can be met:

- Maximum permissible partial filling
- Inspection detail and accuracy
- Documentation method
- Damage-classification system
- Result format

Cost-efficiency is, on the other hand, also an important selection criterion. This factor is influenced by labour and material costs and must be set against inspection benefits. Working safety (Industrial Health & Safety) considerations must also be taken into account. Various potential hazards will result for the persons working in the conduit, depending on the method selected.

The know-how of the staff deployed is also a decisive precondition for the success of drain/sewer inspections. This criterion can be quantified only with difficulty on the basis of company information and references. A method-based preliminary selection, combined with the performance and monitoring of subsequent test deployments in the system to be inspected, is therefore recommended.

Planning recommendations: Construction of future systems

It remains to be noted, with a view to construction of future systems, that adequate drain accessibility at all manhole-shafts is a vital and basic precondition for an inspection, and that supporting provisions for water-management must also be taken into account. This is true, in particular, in cases in which no permanently installed shut-off equipment is available. Temporary water-control provisions generally also necessitate a high level of input for Industrial Health & Safety provisions, since even unmanned inspection inevitably involves the deployment of personnel in and around the channel in the shaft. These aspects must be borne in mind both for the planning of manhole-shaft structures and for conceptual design of the water control safety precautions.

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Source: IKT-eNewsletter June/July 2007

Practical experience and test concepts

Profiled plastic pipe

Besides the so-called classic materials concrete, reinforced concrete, vitrified clay and cast iron, plastic products are increasingly used for the construction, renewal and renovation of drains and sewers. Numerous surveys, research projects and product tests by the IKT – Institute for Underground Infrastructure (Gelsenkirchen, Germany) have dealt with the behaviour of single products under practical and laboratory conditions (cf. [1], [2], [3], [4]). Special emphasis was put on the rehabilitation of sewers, the investigation of special applications, the influence of quality as well as the determination of demands on the dimensioning and testing of pipes and construction methods.

Here, the recently completed IKT research project „Large profiled plastic pipes" (cf. [5]) has set in and offers detailed recommendations for the testing of large profiled pipes in its result. Furthermore, interesting conclusions could be drawn from the practical experience of the network operators as well as from the project-related discussions with users and manufacturers. In the following the substantial findings are summarized.

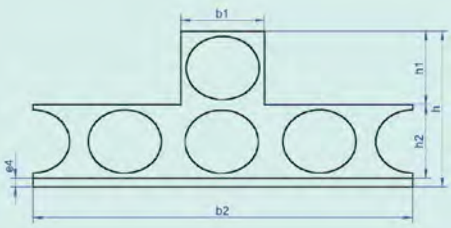
Application of large profiled plastic pipes

For the new construction of drains and sewers, pipes of various materials are offered. Besides pipes made of concrete, reinforced concrete, vitrified clay and cast iron also plastic pipes are increasingly used. If the information by the DWA [6] is taken as a basis, between 2001 and 2004 the proportion of plastic pipes in the German sewer system has grown from around 3 % to around 6 %. In the range of nominal diameters ≥ ND 800 (large pipes) the proportion of plastic pipelines amounts to around 1 %.

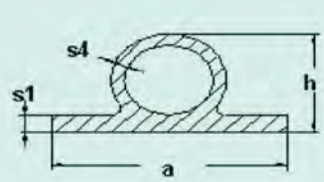
For the range of accessible nominal diameters, besides pipes with monolithic wall structure (solid wall pipes), predominantly pipes with an open wall structure (profiled pipes) are offered. In connection with the IKT-project [5] public sewer network operators predominantly put the comparatively low application rate of large profiled plastic pipes down to insecurities regarding the installation as well as the later behaviour during operation. Essential points in the discussion are the sustainable stability, deformation development as well as bedding requirements, possible difficulties in the installation and the behaviour under point loads. These insecurities are opposed by the intention to use the possible advantages of the offered plastic pipes such as low weight, weldability (PE, PP) and chemical resistance under corresponding structural tasks.

Core-foamed multi-layer pipes as well as pipes with open wall cross sections belong to the product group of profiled plastic pipes. Due to the special construction of their wall structure profiled pipes have a smaller weight compared to solid wall pipes of the same nominal diameter and stiffness. As an example Figure 1 shows a large profiled pipe of the nominal diameter ND 2000 during deformation testing. Figure 2 gives examples of different wall structures of the same nominal diameter, which were also used as testing bodies in connection with the IKT-analysis.

Figure 1: Large profiled plastic pipe ND 2000 during the experiment: pipe deformation and water tightness testing of the connections

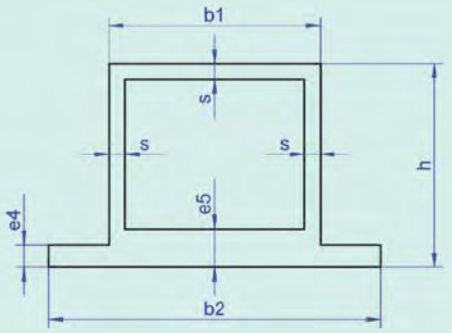


a) Example 1 of a profile: profile height h = 123 mm, partial heights $h_1 = h_2$ = 58 mm, profile width b_1 = 66 mm, profile distance b_2 = 300 mm, main wall thickness e_4 = 7 mm (dimensions according to [7])



b) Example 2 of a profile: profile height h = 76.0 mm, main wall thickness s_1 = 15.0 mm, hose jacketing s_4 = 10.0 mm (dimensions according to [8])

Figure 2: Wall sections (examples) of large profiled plastic pipes (ND 2000)



Example 3 of a profile: profile height h = 103 mm, profile width b_1 = 110 mm, profile distance b_2 = 180 mm, profile wall thickness s = 8 mm, wall thickness of the inner layer e_4 = 11,0 mm, wall thickness of the inner layer under a hollow profile e_5 = 19 mm (dimensions according to [9])

Figure 2c: Wall sections (examples) of large profiled plastic pipes (ND 2000)

Practical experience

To determine the actual state of plastic pipelines, which have already been installed, with regards to possible precarious features sewer inspections were carried out and inspection videos of non-accessible sections were sifted. In connection with the inspection of passages with large profiled pipes, 24 sections with a total length of around 1.5 km were inspected and additionally, the cross sections were comprehensively measured. The videos viewed contained TV inspections of altogether 248 sections with a total length of around 10 km. Weak points, cases of damage (such as leaks, for example) or other peculiarities that were found were identified as well as pictured and described. In the following substantial precarious features in the area of pipes, pipe joints, side inlets, manholes and manhole constructions are compiled.

In connection with the sewer inspections the internal diameter of accessible pipes was measured and analysed in the horizontal as well as the vertical direction by employing a telescopic measuring stick in regular intervals (beginning, middle and ending of the pipe). Only in one of the 24 sections the permissible limiting value of deformation (permitted δ_v = 6 %) according to [10] was exceeded. In comparison the analysis of the inspection videos for non-accessible sewers showed noticeable deformation figures such as arch profiles, three- or four wave figures, upward ovalisation. An extreme ovalisation of around 30 %, however, was only observed in one single, 5 m long section of the total inspected length of approximately 10 km. To some extent misalignments appeared in the non-accessible sewers. Presumably, they originate from the installation process, for instance, from insufficient positioning. Local deformations that can probably also be led back to deficient construction, such as square timber that remained in the ground, were hardly observed in the area of the pipe invert.

Leaks inside the pipe shaft were only observed in single cases in places with water dripping in. It could not be revealed in what sense these lacks can be put down to damages during installation or to point loads. In the accessible area no leaks whatsoever could be visually observed.

In large pipes as well as non-accessible pipes displaced joints (maximum heights: 3 cm) were determined in the area of pipe joints. They were probably caused by diameter tolerances that are linked with the manufacturing process (cf. Figure 3).

Figure 3: Pipe joint with a displacement of 3 cm (ND 2000, year of construction: 1999)

Welding seams of varying width showed at pipe joints that were created by extrusion. A deflection in the pipe joint could be the reason for this variation, for example. So as a consequence, the butt joint has a different width in the direction of the circumference. In connection with the sewer inspection as well the sifting of TV inspection videos, however, no leaks were detected. At some pipe joints, which were created with the helical-coil-welding-socket method, weld metal was visible. Presumably, this resulted from a deviation during the connection of the pipes. Leaks were not noticed in these areas.
Within the scope of sewer inspections as well as of the sifting of inspection videos precarious features at the side inlets were observed only in exceptional cases. So in large pipes only in one case an uneven cutting edge at the inlets could be noticed and in another case an extremely wide welding seam. In non-accessible pipes, on the other hand, leaking connection areas could be observed due to infiltration of groundwater.
Clear weak points showed on manholes with a change of material from PE pipes to shafts of concrete or brickwork. Here, precarious features in the form of cracks, cleavages, material removal and root ingress were observed in the transition area between the pipe and the shaft construction (cf. Figure 4).

a) Crack in the area of the manhole (ND 1600, year of construction 1999)

b) Crack between pipe (ND 500, year of construction 1985) and brickwork manhole channel

c) Material removal in the mortar joint between pipe (ND 700, year of construction: unknown) and brickwork manhole channel

Figure 4: Precarious features at manholes

Usually leaks within manhole constructions occurred in the area of the material transition between PE manhole base unit and the installed concrete shaft ring or brickwork. As a cause mostly the use of an deficient sealing medium or a deficient installation process, e.g. sealing with wrong direction of installation, could be assumed. In the vicinity of material transition from PE to brickwork no infiltration could be observed, but leaks must be expected, because of bad connection characteristics between those materials.

In addition to sewer inspections and the sifting of TV inspection videos, also interviews with approximately 130 public sewer network operators (local authorities and water associations) were made in order to include further experience by the network operators in planning, construction and operation. Here it became clear that on the side of the sewer network operators there are special uncertainties with regards to pipe stability, feasibility of soil compaction requirements and necessary company know-how in the installation, especially in soil compaction and positioning. Furthermore, they pointed at possible difficulties during rehabilitation (method and costs). The low weight and the weldability as well as positive experience in sewer cleaning and water tightness were mentioned as advantages on the other hand. It has to be pointed out that numerous sewer network operators reported noticeable deformations of the cross section, but in connection with the approval or inspection the cross sections were only infrequently measured. In most cases no statements on the development of the deformation of plastic pipes with reference to the time were made.

In order to include the current practice of dimensioning of large profiled plastic pipes, some of the available static calculations were analysed with regards to the calculation assumptions and conditions as well as the calculative verification. Altogether, the analysis of the static calculations of twelve completed constructions shows that in the past the installation conditions, e.g. soil groups and degree of compaction, had been determined in a very optimistic way; the verification limits (especially deformation- and stability verification) had usually been exploited and the possibility of a profile collapse had by no means been taken into account.

Furthermore, it was found out that the selection of a cross section for large profiled plastic pipes usually derives from the limiting conditions of the project. That means that the profiling corresponds to the static requirements of the individual application. Reserves for unexpected incidents such as changes of soil groups, that are detected on the construction site later on, deviations in the selection of the lining type and the geometry of the trenches are usually not available. That means that special importance is attached to the static calculation of the strongly exploited construction [4].

The fact that the different material- or pipe characteristics of the plastic pipes are often unknown to the network operators is to be considered particularly critical. Furthermore, on the site an identification of the installed materials is basically left out. Usually the network operator summarizes the different materials under the term „plastic" so problems with a material or pipe type are often related to the entire material family.
The questions raised in connection with the in-situ investigations, interviews and construction site analyses were summarized in the following five main topics with reference to the research project:

- condition assessment in situ
- deformation of the cross section
- influence from operation loads
- (time-dependent) stability collapse
- local external loads (point loads).

The development of the test concepts and their realisation is presented in detail in [5]. As an example, the following deals with condition assessment in connection with construction approval or warranty check, and possible investigations concerning stability collapse of profiled pipes.

Measurement of deformation and approval

DWA standard A 127 (cf. [12]) classifies pipes as flexible if, due to their deformation, the surrounding soil is part of the bearing system. Correspondingly, to verify long-term deformations a vertical change of diameter of 6 % (or 9 % when looking at additional verification) is permitted. Also regarding the effects of extreme deformations on the functional safety and water tightness, special importance is attached to assessing pipe deformations. Starting from the current state of experience with deformation measuring data, a method for acquiring and analysing deformation measuring data has been developed, which can be summarized as follows:

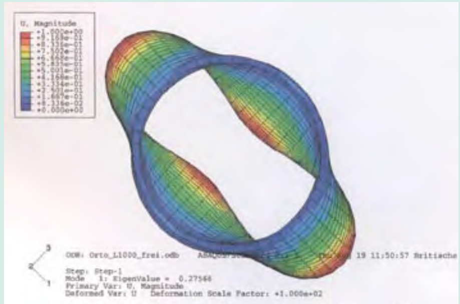
1. Measuring is carried out by employing a telescopic measuring stick, by means of which the internal pipe diameter is measured in regular intervals or locations with precarious features in the horizontal and vertical direction (cf. Figure 5).
2. The measuring data is processed and is recorded graphically (cf. Figure 6). Here, the horizontally and vertically measured diameter values are plotted on the y-axis; the stations are to be taken from the x-axis.
3. A permissible deformation range (DR) is chosen, e.g. from the regulations in [12] or from the static calculation (DR = 2 x permissible δ_V), and is inserted into the diagram by means of two horizontal lines. Since the actual diameter of the undeformed pipe does not have to correspond to the target diameter according to the manufacturer, the deformation range is oriented at the mean value of all measuring values by especially taking into account extreme deformations (cf. [4]).
4. Spots with extraordinary deformations or figures are identified as critical pipe cross sections for further observation and are correspondingly marked in the analysis of the measuring data. With regards to a possible long-term stability collapse in future inspections these cross sections should generally be assessed in detail and should be checked for possible changes or increase of deformation.

Figure 5a: Determination of the horizontal diameter

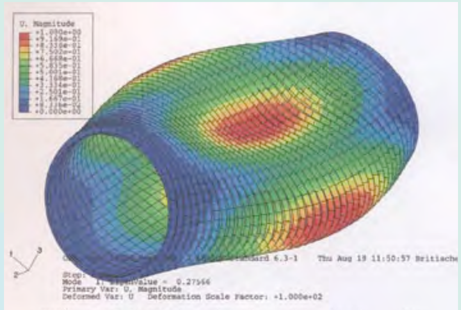
Large profiled plastic pipes

Figure 5b: Determination of the vertical diameter

a scale of 1:1. On this basis calculation bases for the FEM model developed for the mathematical stability proof can be calibrated and the applicability of existing calculation concepts can be analysed. Figures 7 and 8 show the deformation of pipes at the end of one of the external water pressure experiments that have been carried out as an example. They also show the result of a corresponding FEM calculation.



a) Front view



b) Isometric view

Figure 8: Buckling shape of an orthotropic shell (Ultra Rib 2, ND 300), from [13]

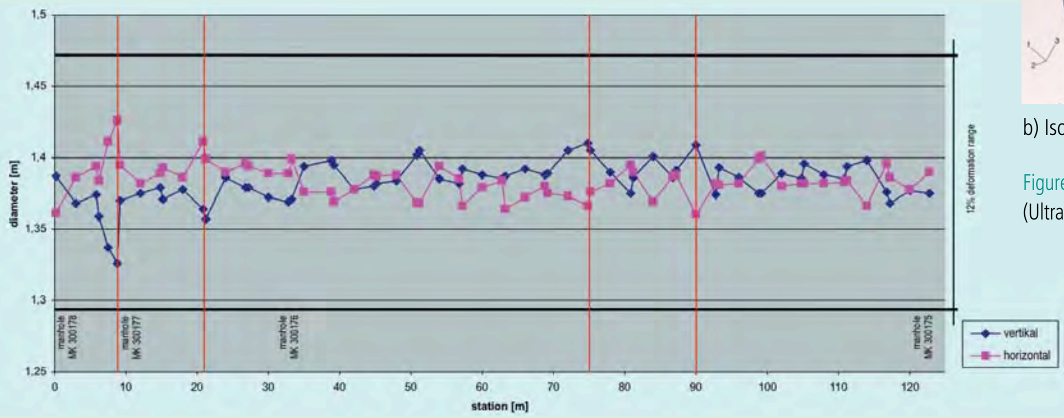


Figure 6: Horizontal and vertical diameter values compared to the permissible deformation range (long-term, DR = 2 x δ_v), example

Time-dependent stability collapse

Basically, the stability behaviour of large pipes can also be determined by large-scale experiments of the scale 1:1. However these experiments, under hydrostatic external pressure at the IKT large-scale experimental rig, for example, hardly seem economically efficient. Usually a mathematical stability proof is advisable when verifying the calculation model by small-scale model experiments. A corresponding concept was developed by the IKT and the University of Applied Sciences in Münster (field of statics and constructional computing).

Global stability collapse is investigated by taking into account the special material behaviour by means of crown pressure experiments and buckling experiments with unbedded, profiled plastic pipes of the nominal diameter ND 300 on

a) undeformed pipe cross section before the experiment

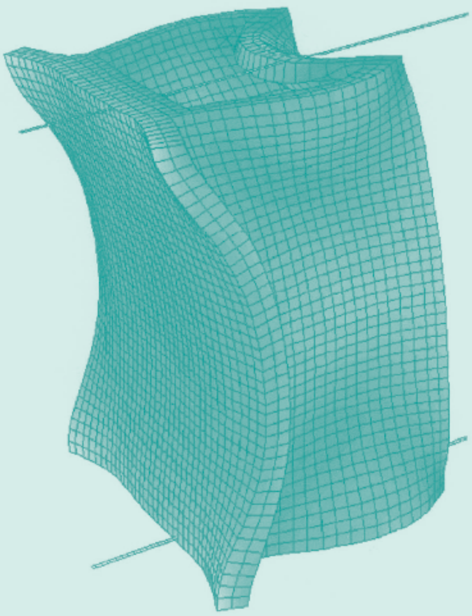
b) deformed pipe cross section after the experiment

Figure 7: Test pipe in the external water pressure experiment (Ultra Rib 2, ND 300)

The only aspect that remains unclear in the external water pressure experiment, however, is the influence occurring with complex profile geometries and high axial force loading that can develop with bedded pipes. Thus, also a profile collapse before or together with global collapse cannot be excluded as well as the likeliness that material behaviour is only insufficiently considered. Also the large pipes that were investigated partially showed clear deviations from the target geometry (measurement of wall structure and nominal diameter) due to production. So a weakening of the profile cross section and – without further safety considerations and analyses of weak points – corresponding risks with mathematical use of the theoretical profile shape can be expected.

For this reason, a test concept was developed, by means of which a distinct deformation of profile samples (pressure cartridge) is provoked under high axial force loading. Based on this, the significance of the FEM model can be checked. To minimise the bending moment, which is a consequence of the curvature of the testing body, small-sized wall sections are used for the experiments. The result of experiments that were carried out as an example showed good correspondence between the deformation types in the experiment and the deformation states simulated by means of FEM calculations (cf. Figure 9). Imperfections of the profile geometry created by local load introduction are developed by lateral pressure experiments (cf. [5]) on similar testing bodies and are aligned with the FEM model.

a) Deformation in the experiment



b) Result of an FEM calculation, from [14]

Figure 9: Deformation of the profile sample under vertical load at the cross sections

Conclusion and outlook

Against the background of the practical experience, laboratory tests and mathematical analyses the following **conclusion** can be drawn for **practice**:

The **installation quality** is decisive for the safety of the entire system of pipeline, bedding and shaft constructions. Besides deformations of the cross section, in situ also **misalignments** were often observed and in few cases **local deformations**. In connection with the actual construction, special care should be taken of an adequate positional safety of the pipes without disturbing bodies (e.g. squared timber), with a consistent soil compaction and the minimisation of pre-deformation (e.g. due to solar irradiation). **Point loads** are a special case that is difficult to describe within the scope of testing. For example, this applies to the information about the size of the catchment area of the of possible disturbing bodies and the number of their contact spots to the pipe.

The analysis of the **static calculation** of twelve completed construction measures showed that in the past the installation conditions, such as soil groups and level of compaction, were determined very optimistically, the verification limits – especially deformation- and stability proof – were exploited. The possibility of a profile collapse was not taken into consideration at all.

Leaks within the pipe shaft were hardly observed. Only in two single cases dripping water could be seen in the crown area of non-accessible sections. **Material transitions** from PE to concrete or brickwork cannot be regarded as special weak points for the water tightness of the entire system. Here, the solutions for water tight material transitions, which are offered on the market in connection with system tests, should be analysed with regards to their basic suitability. Concerning the construction approval, the question for manageable methods for water tightness testing raises in these transition areas. **Manholes and changes of material in shaft superstructures** should already be scrutinised more during planning, the construction period and the product development.

A more detailled inspection of large plastic pipes is hardly taking place. Deformations on large profiled plastic pipes are scarcely measured in connection with the approval of the construction and during the operation stage. Due to the operational situation, e.g. partial filling as well as the slippery surface (slip hazard), sewers are only inspected in single cases. **Critical deformation states**, large vertical deformations, for instance, can only be assessed reliably if also information about the delivered quality, the installation and the temporal development of the deformation is available. Thus, special importance is attached to the approval of the delivered goods, the approval of the construction as well as the regular inspection and measuring of the cross section – for noticeably great deformations. In order to achieve **significant inspection results** in situ with arguably effort a combination of visual inspection and deformation measuring is recommended. Then, on this basis, critical areas for further detailed observations can be identified.

The network operators seem to have particular uncertainties regarding the demands on material quality (e.g. PE-HD and PE 80/100), the connection technique (e.g. welding method or sockets) and on the special qualification of the construction companies.

Source: Bosseler, Sokoll, Falter, Holthoff: bi UmweltBau 5/2006

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Pipes under pressure

Pressurized waste-water lines (rising mains) can, to a certain extent, be seen as the „neglected" part of the pipeline family. In terms of cleaning and maintenance, they frequently lose out. Many system operators start to feel uncertain where the necessary time for cleaning, and the selection of a suitable method, are concerned. The IKT decided to improve this situation: together with sixteen system operators, the institute examined the potentials and available techniques for the cleaning of pressurized waster-water lines.

The results of the recently completed „Pressurized waste-water lines - Potentials and methods for their cleaning" research project [1] are now available.

The special features of pressurized conduits

The need for the construction of pressurized lines (rising mains) occurs, in particular, in areas of low population density or of inadequate gradient potentials. Around 90 percent of system operators in the German state of North Rhine-Westphalia (NRW) operate pressurized lines (rising mains). Such lines account only for some four percent of the total length of the public waste-water system in NRW (3491 km of pressurized lines), however. Information supplied by operators indicates that they posses only little experience with the cleaning of such conduits.

Cleaning activities in pressurized lines (rising mains) are complicated by the absence of maintenance/inspection openings, gradient changes, high/low points and bends in such conduits, and by their predominantly complete filling. Since many system operators are uncertain of just when cleaning of such lines is necessary, and what methods they can use, cleaning and maintenance of these installations is generally restricted to the pumping stations and venting valves.

It is thus possible for problems and faults, such as the following, to occur during operation of pressurized lines (rising mains):

- Depositions (of grease, for example), which can cause loss of open pipe cross-section, coupled with reduced pump delivery rates and rising energy costs;
- Grease-blockage of venting valves, with resultant defective valve-functioning and
- Blockages which can result in complete non-functioning of the conduit.

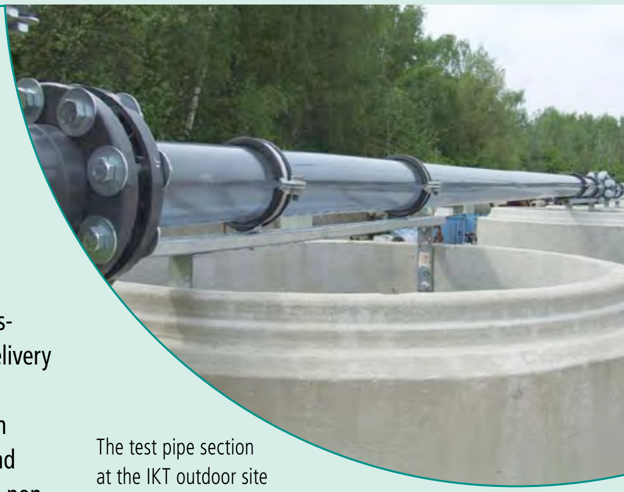
Concealed blockage [2]

Undesirable evolution of hydrogen sulfide can produce a problem that will quite quickly draw the attention of the public. This gas is generated as a result of stagnation of the waste-water in case of prolonged residence times in the pipe. Even at low concentrations, emission of hydrogen sulfide gas into the atmosphere in the surrounding area can cause an unpleasant smell of bad eggs. Touchy citizens will then quickly reach for the telephone in order to complain to the system operator. Many people associate unpleasant odours from the drain system with inadequate cleaning of the conduits. The question was, however, the extent to which poor cleaning really is the reason for the generation of hydrogen sulfide.

Many odour-generating processes take place in the sewer slime

Procedure

The IKT researchers set themselves the target of cataloguing, with the greatest possible practical orientation, the potentials for and limitations on use of the various methods, and assessing their cleaning performance. Reference data for the costs involved was also to be obtained and,



The test pipe section at the IKT outdoor site

finally, the advantages and disadvantages of the diverse methods derived. The project therefore focused on test deployments of various techniques, which were observed and evaluated in cooperation with sixteen system operators.

It was possible to test selected cleaning procedures at a number of different locations:

- Pressurized lines operated by the participating operators
- The test pipe-section at the IKT site and
- The test pipe-section at the Porta Westfalica (Germany) treatment plant.

The practical tests performed on the operators' systems primarily enabled the IKT researchers to obtain information on the handling of the various methods and on the necessary technical preconditions.

The IKT test section specially developed for this project was used in order to simulate various deposition situations and to test the methods in the context of cleaning trials under identical boundary conditions. It was thus possible to derive comparative information concerning, for example, cleaning performance and physical transport characteristics. The IKT researchers were able here to simulate, and investigate in more detail, problems which had not been answered during the practical deployments.

The test section at the treatment plant was colonized with sewer slime to permit supplementary cleaning tests. This test section conveys waste-water from the treatment plant's inflow, unlike the IKT test section, which is operated with fresh water.

Methods examined

The participating system operators decided to include the five following cleaning methods in the project program:

- *Impuls-Spül-Verfahren* (pulse-flushing method)
- Pigging
- High-pressure cleaning using a drain flushing nozzle
- The „Lipolyt 2000" biological cleaning method and
- Generation of elevated flow velocities by means of an ejector and a hydrant

The main focus was on testing of the *Impuls-Spül-Verfahren* (pulse-flushing) and the pigging method, procedures specially developed for pressurized lines (rising mains), alongside the high-pressure flushing nozzle widely used in gravity drains. All the methods were assessed both in the system operators' pressurized lines and in test pipe sections. A hydrant and an ejector were also used for flushing tests in the IKT test section.

The definitive reason for also testing a biological method in existing pressurized lines (rising mains) can be found in its field of application: in addition to reducing, or even eliminating, organic depositions, it is also said to suppress the formation of hydrogen sulfide, and thus help in combating unpleasant odours.

Feeding of compressed air during a pulse-flushing operation

Pulse-flushing: In the patented *Impuls-Spül-Verfahren* (pulse-flushing method), large volumes of compressed air are injected in pulses into the conduit. It was noted in the IKT test pipe section that turbulent mixtures of air and water of a length of several meters occurred, filling the entire pipe cross-section and passing at high flow velocities through the pipe.

Pigging: In the pigging method, a cleaning-pig is inserted into the pressurized line (rising main) and propelled through it by a propellant fluid (generally water). This dislodges depositions from the pipe wall and conveys them out of the pipe. A number of cleaning cycles, using different types of pig, are performed, depending on the fouling situation. The pigs differ in terms of their materials, diameter, hardness and surface characteristics.

Insertion of a foam pig

High-pressure cleaning: It is necessary, if a high-pressure flushing nozzle is to be used, to take the pressurized line (rising main) out of operation and to open a manhole. The flushing hose is then inserted into the line via this opening. Standard drain-flushing-vehicle hoses generally vary in length between 80 and 120 meters. Actual operating range („reach") is usually significantly less than this, however, due to frictional resistance caused by flushing sockets, the pipe wall, and any depositions present. The limited reach of such flushing hoses means that maintenance and inspection manholes are necessary at short, regular intervals.

High-pressure flushing nozzle

The „Lipolyt 2000" biological method: According to information supplied by the manufacturer, this product contains microorganisms, enzymes and a carrier material. The microorganisms, on the one hand, are intended to break down and dislodge organic depositions. Their other function, on the other hand, is to expel sulfide-producers and thus prevent the evolution of hydrogen sulfide. All sulfide-production points, i.e., all pump shafts and siphons, are „inoculated" with this product.

Input of „Lipolyt 2000" into a pump shaft

Flushing using ejector and hydrant: In individual tests at the IKT test section, a hydrant and an ejector were used to generate elevated flow velocities. In the ejector method, water in a tank (or the outflow in a pipeline) is accelerated by generating a partial vacuum. The water to be conveyed is fed into the ejector via the water-intake connection. The high-pressure hose of a flusher vehicle, via which the pressurized water is conveyed in the nozzle element inside the ejector, is connected to the propellant-water connection point. The propellant water accelerated via the nozzle elements produces a partial vacuum and entrains the water fed via the suction connection.

Ejector

The IKT test section

The IKT test pipe section consists of an around 30 m long, virtually horizontal „standard zone" and an around 30 m long „extreme zone". The extreme zone features high-points and low-points, and bends of between 45° and 90° (in the form of PVC elbows).

Various depositions were applied in the standard zone, in order to permit observation of the dislodging and mobilization of such depositions. The onward conveyance of dislodged depositions was recorded in the extreme zone.

The simulated deposition situations were intended, on the one hand, to cover a broad range of possible fouling situations and, on the other hand, to provide extreme conditions in order to permit approximate assessment of the performance limits of the various methods. Adhering depositions consisting of grease and mixtures of grease and sand, highly solidified depositions in the form of liquid bedding material and floor-topping, and non-cohesive, unsolidified depositions consisting of gravelly sand, progressing to gravel and to larger individual stones, were thus positioned in the test section. In addition, blockage by sandy, gravelly fractions, combined with fibrous, binding elements, was also simulated.

Results

Impuls-Spül-Verfahren (Pulse-flushing method)

The pulse-flushing technique exhibited the highest conveying performance in the test section, but its dislodging force was lower than that of the pigging method and the high-pressure flushing nozzle. It was able, for example, to convey depositions such as sand and gravel, and also individual larger stones, but not to completely remove tightly adhering fouling, such as grease.

The conveying rates achieved by the *Impuls-Spül-Verfahren* (pulse-flushing method) and recorded in the test section could, possibly, also decrease with increasing cleaning length, other pipe materials and other conduit configurations. The basic precondition for the effectiveness of pulse flushing is therefore the setting-up of an adequate number of flushing stations, and that the pulses can be generated at sufficiently high pressures and volumes.

One advantage of the *Impuls-Spül-Verfahren* (pulse-flushing method) is that fact that it is generally not necessary to shut down the pumping station.

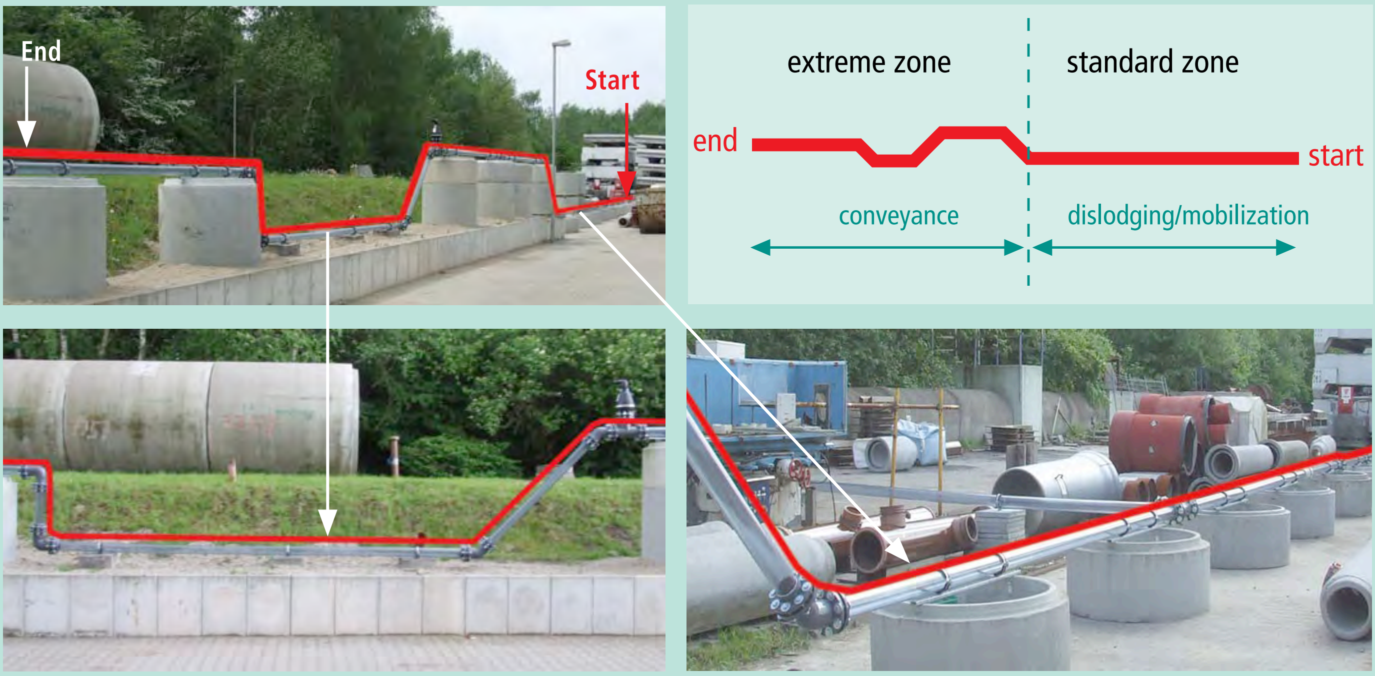
Pigging

Pigging, alongside the high-pressure flushing nozzle, exhibited the highest dislodging force. It was able, for example, to completely remove even powerfully adhering depositions of grease in the test section. The precondition for best-possible cleaning performance is, however, the use of a pig tailored to the particular deposition conditions. Conveying performance was significantly better than that of the high-pressure flushing nozzle, with the result that pigs were also able to remove heavy sand depositions easily. Conveying difficulties can occur under extreme conditions, featuring tight bends combined with heavy or voluminous depositions.

One advantage of pigging is found in its high dislodging force and in the fact that it is, in many cases, possible to clean several kilometers of line length in a single operation.

High-pressure flushing nozzle

The high-pressure flushing nozzle also exhibited good dislodging power in the test section, but the nozzle's conveying performance was severely restricted, as a result of the flushing water building up in the conduit. In addition, both the trials performed in the test section and practical tests demonstrated that cleaning using high-pressure flushing nozzles involves a high level of work input and that there are, in addition, clear limits on utilization. The reach of the flushing



The IKT test section: transparent Plexiglas pipes, DN 100, length approx. 60 m

Deposition situation		Cleaning performance			
		pulse-flushing	Pigging	HP nozzle	Ejector/hydrant
non-cohesive, non-solidified	Gravelly sand (0/8)	+ [2]	+ [2]	+ [2]	+ [2]
	Gravel (20/40)	+ [2]	~ [2]	– [2]	– [2]
	Stones	+ [1|2]	~ [2]	No test	No test
adhesive	Sewer slime	o [1|2|3]	+ [3]	+ [1]	No test
	Grease/sand	o [2]	+ [2]	o [2]	– [2]
	Grease	– [1|2]	+ [2]	+ [2]	– [2]
solidified	Liquid bedding material*	+ [2]	+ [2]	No test	No test
	Floor-topping*	+ [2]	~ [2]	– [2]	– [2]
solidified, sealing	Blockage	– [2]	– [2]	+ [2]	– [2]

Cleaning performance of various methods from cleaning tests performed in-situ, at the IKT and in Porta Westfalica

* Not classifiable as an encrustation, due to low surface roughness

\+ Dislodging and conveyance possible, (practically) complete removal

o Dislodging and conveyance largely possible

– Dislodging not possible or possible to only a limited extent, and/or conveyance not possible or possible only to a limited extent

~ Dislodging possible, conveyance problem at angled elements

1 Results from practical test

2 Results from IKT test section, PVC DN 100, L=60 m

3 Results from Porta Westfalica (Germany) test section, HDPE DN 100, L=100 m

hose is, for example, limited, with the consequence that maintenance and inspection shafts are necessary at short intervals.

The fact that even the simulated blockages were eliminated should be mentioned as a basic advantage of the high-pressure flushing nozzle over pulse-flushing and pigging. In practice, however, the precondition for this is that the nozzle can actually be fed into the pipeline as far as the location of the blockage.

The „Lipolyt 2000" biological method

It was not possible, in the context of four practical tests, to clearly verify the effectiveness of the „Lipolyt 2000" biological product. In three tests, the effects stated by the supplier, viz.:

- Breakdown of depositions and surface slime in the shaft
- Reduction of sewer slime in the line and
- Avoidance of hydrogen sulfide formation

did not occur with any particular clarity.

In the fourth test, still continuing hydrogen sulfide measurements should also be augmented at a warmer period of the year.

Information has, however, been received from system operators, stating that the use of this product has reduced depositions at pumping stations and odour problems caused by hydrogen sulfide.

Numerous biological methods for combating of odours and/or for breakdown of organic depositions are available on the market. The results obtained with the Lipolyt 2000 product tested cannot be assumed without modification for other products and methods, due to their differing compositions.

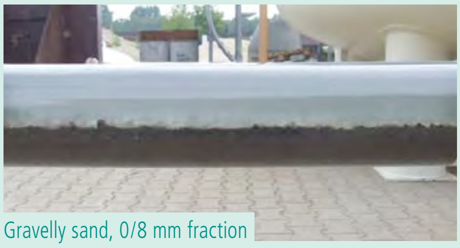
Elevation of flow velocities using ejector and hydrant

The connection of an ejector and a hydrant to the test section succeeded only to a limited extent in generating elevated flow velocities. Non-cohesive depositions of sand were flushed out without difficulty, whereas gravelly and adhering depositions consisting of grease or mixtures of sand and grease remained unaffected. The potential applications are restricted to systems with only slight height differences in the pressurized lines (rising mains) and small conduit diameters, due to the limited delivery heads and delivery rates of ejectors and hydrants.

Evaluation

The basis for the evaluation is provided, in particular, by the experience gained from tests in the IKT test section. It should be noted when studying the cleaning performances shown that the simulated deposition situations in the test section in some cases involved extreme conditions. As the experience of system operators indicates, sewer slime and grease depositions can be regarded as more frequently occurring


Grease


Gravelly sand, 0/8 mm fraction


Blockage[1]

Examples of depositions from the IKT test section

deposition situations, and blockages do occur in some cases, whereas severe depositions of sand or gravel are rarer.

The pulse-flushing, pigging, high-pressure flushing nozzle, and ejector-flushing methods can be directly compared in the assessment. These are techniques which are used, and were tested in the IKT test section, in case of the existence of depositions of mineral and/or organic origin. The biological process examined, on the other hand, should be assessed separately, due to its applications, which are primarily found in the avoidance of organic fouling and of elimination of hydrogen sulfide evolution.

It is possible to state by way of conclusion from the results of these tests that both pulse-flushing and pigging are suitable methods for cleaning of pressurized waste-water lines (rising mains), but that each method has its own particular advantages and disadvantages.

Flushing operations using high-pressure flushing nozzles manifested an extremely good dislodging performance, but these systems are subject to serious limitations in terms of reach. Ejectors and hydrants achieved acceptable cleaning results only in removal of easily detachable fouling.

It is possible to eliminate or reduce the problem of odours caused by evolution of hydrogen sulfide only for a short time, at best, using the mechanical cleaning procedures. Excessively long waste-water residence times in the pressurized line (rising main) should be regarded more as the cause of production of odours from hydrogen sulfide than the frequency of or lack of cleaning.

Results available on the Internet

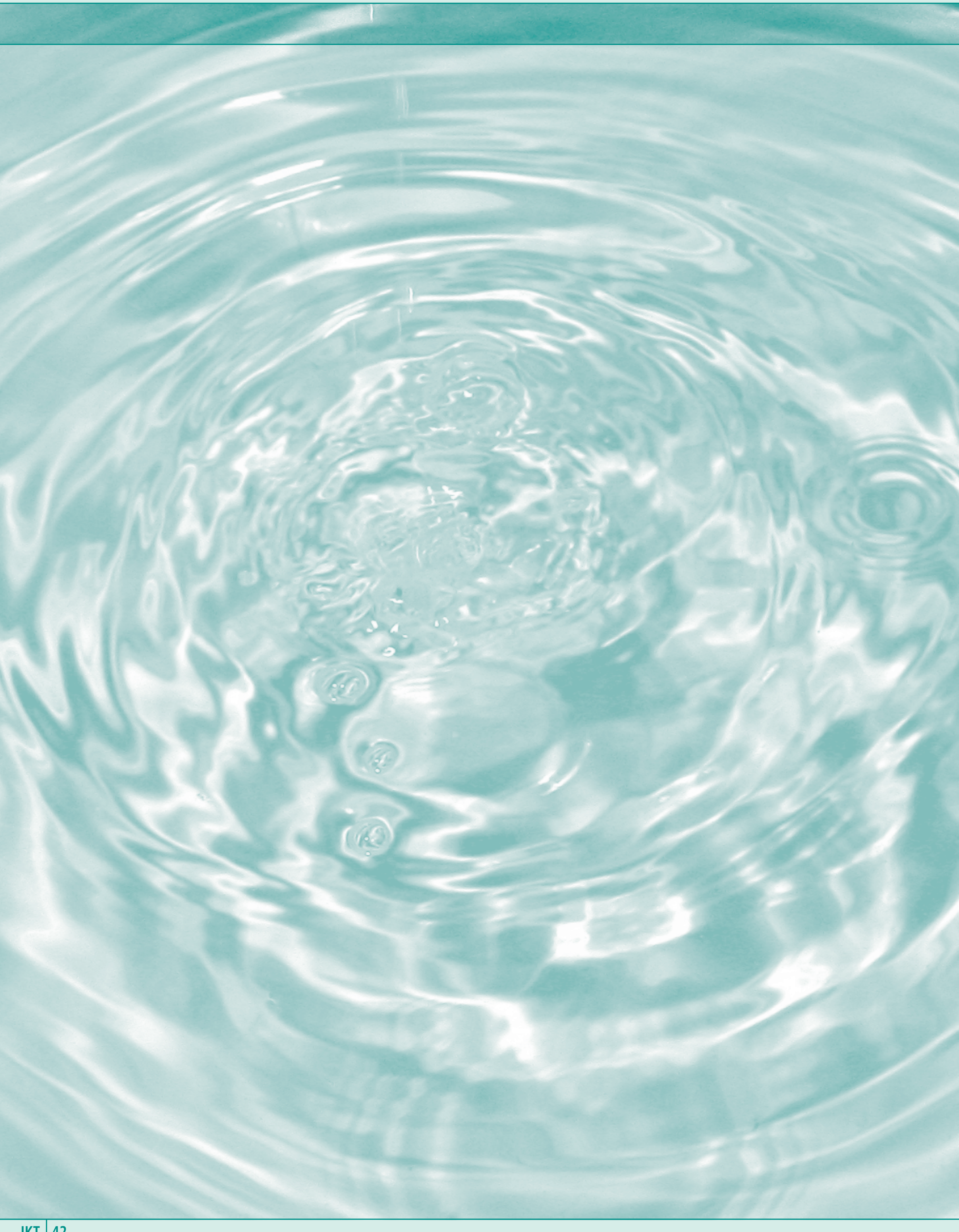
This article provides only a summary of the results of the „Pressurized waste-water lines - Potentials and methods for their cleaning“ project. Both the abbreviated and the complete version are available, with more details and all results, for download from the Internet at www.ikt.de

Source: IKT eNewsletter, March 2007

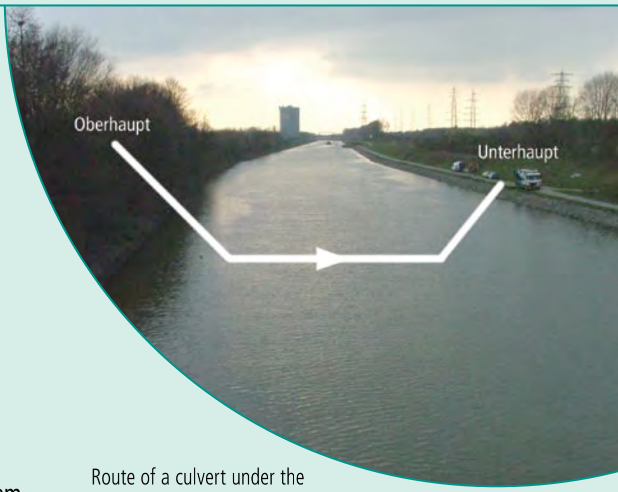
[1] mixture consisting of gravelly sand, dead leaves, fibrous materials [bast, hemp, toilet paper], bentonite particles and water

Bibliography

[1] Bosseler, B.; Harting, K.: Abwasserdruckleitungen – Möglichkeiten und Verfahren zur Reinigung („Pressurized waste-water lines - Potentials and methods for their cleaning“); IKT – Institute for Underground Infrastructure, on behalf of the NRW Ministry of the Environment (MUNLV), 2006
[2] Illustration courtesy of the Municipality of Billerbeck, 2006



Waste-water culverts: The forgotten feature



Route of a culvert under the Rhine-Herne Canal in Oberhausen (length 90 m; diameter 1.0 m

Wherever features such as streams, rivers and tunnels prevent the natural flow of waste-water, culverts perform the task of conducting the waste-water under the obstruction to be traversed. Completely filled culverts confront system operators with a number of challenges when inspection and cleaning of these special structures become necessary. For the „Use of Ejector-Technology for Inspection and Cleaning of Culverts" research project [1], the IKT focused its attention on these problems.

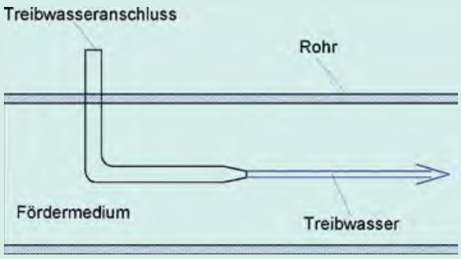
Inspection not the main problem

Prior to the start of the project, the IKT performed a survey of 208 system operators from the German state of North Rhine-Westphalia to obtain basic information on experience with waste-water culverts [2]. This survey indicated that water control, and not inspection, is the central problem:

- The maximum available inspection periods when culvert feeders are flanged off, with back build-up of water, is too short for TV-based inspection.
- Overpassage of the waste-water causes great technical, economic and organizational input and is therefore not a method used by the operators surveyed.
- Through-passage of the waste-water using hoses or pipes is a method conceived for use in gravity lines and is also not used by the system operators surveyed in the case of culverts.

It is therefore necessary to find new technical solutions, since both overpassage and through-passage of waste-water for water control are either not practicable or have, at least, not been tested, using existing technology. One option, as an initial step, is the use of tools which have already proven their capabilities in similar applications. One such aid is the ejector nozzle. Such nozzles can be used to clean and drain the culvert, and to keep it free of waste-water for inspection. For the „Waste-water culverts" research project [1], the IKT researchers analyzed the practical use of ejector technology both in laboratory tests and in the context of system operators' inspection operations.

Multi-jet ejector: high-pressure-water hose connection (No. 1, red arrow), intake aperture (No. 2, blue arrow), outlet aperture (No. 3, green arrow; propellant water [Q_{propel}] and conveyed fluid [Q_{convey}] exit at this point)



The operating principle of a liquid-jet-liquid ejector, ejector

Ejectors: the technology

A common application for ejector systems can be found in eductor-jet pumps, in which the liquid to be conveyed is accelerated by an added liquid, and is thus pumped (liquid-jet-liquid ejectors). Ejectors can, however, also be used for conveyance of gases and solids. The ejectors used in management and operation of drains and sewer take the form of liquid-jet-liquid ejectors. The pressurized water from the flusher vehicle is fed to the ejector via a propellant connection. The water pressure is converted to kinetic energy in the ejector nozzle, and the propellant water is thus accelerated. The directional flow of propellant water thus generated entrains the liquid of the added conveyed fluid (waste-water, for example) as a result of the viscosity of the liquid. Along the remainder of the flow path, the propellant water and the conveyed fluid mix, until complete pulse equalization is reached.

The advantage of the use of ejector technology in drains and sewers can be found in the fact that an extremely high pump capacity generated using existing technology can be exploited, thanks to the flusher vehicles already available for conduit cleaning. Ejector systems also offer benefits in terms of working safety, since there is no danger of explosion, and, in addition, the equipment is already familiar from daily conduit-cleaning operations and can be used without any need for special instruction or training of the workforce.

Ejectors in practice

In drain and sewer management, ejectors can be used both as cleaning tools and as pumps. Only a few system operators possess experience with ejector technology. In the framework of this project, this experience was both surveyed in the context of in-person talks and registered and documented by means of visits to selected operators. In addition, the use of ejector systems for water control at culverts was also observed at the worksites of three system operators in Ratingen, Arnsberg and Oberhausen, in order to include examples of practical application.

In the German state of Lower Saxony, system operators from Göttingen and Hanover possess good experience with the use of ejectors. In 1981, Stadtentwässerung Göttingen (Göttingen Municipal Drainage Authority) for the first time used an ejector for pumping off of sludge. This organization nowadays uses ejectors for cleaning of conduits of DN 250 and above. This cleaning procedure is also known as „soft cleaning". In their „pump" function, ejectors are also used for filling of high-pressure vehicles, for the location of flooded road routes and also for drainage of culverts. In Hanover, ejectors are in successful use for cleaning of drain and sewer conduits of DN 800 and above. The responsible engineers here emphasize these systems' high conveying performance in partially filled conduits.

Use of a filter ejector for filling of a high-pressure cleaning vehicle with water from the River Leine, 1982

A number of system operators from North Rhine-Westphalia reported unsatisfactory experience with the use of ejectors for conduit cleaning, stating as their reasons poor tractive effort with only inadequate cleaning performance. In some cases, the ejector tube also became blocked by large stones. Bar-cages positioned in front of the ejector intake can provide a remedy for this. The use of a standard ejector as a pump for discharge of digester tanks is a special application mentioned. Using an ejector, the sludge from a digester can be completely discharged within two working days.

The three pilot projects in Ratingen, Arnsberg and Oberhausen made it possible to confirm the positive experience gained in other federal states of Germany and to apply it to culverts in North Rhine-Westphalia. Provided the ejector technology was correctly used, it was possible to clean, drain and inspect the culverts within a single working day.

Ejectors are particularly suitable for cleaning of culverts of diameters greater than DN 400. The water from the completely filled culvert is used by the ejectors in the cleaning process and depositions are flushed out of the culvert.

Ejector with connection points on both sides

In none of these special structures was the precise location of the lowest point in the culvert known. It was necessary, in order to achieve complete culvert drainage, to repeatedly relocate an ejector iteratively until the lowest point in the culvert was found. Contrary to the information supplied by the system operators questioned in [2], according to which the maximum possible inspection periods available for TV inspection are too short when the method of flanging off of

Left: An ejector in use
Right: Insertion of the inspection camera

culvert feeders with build-up of water is used, it was possible in all these three pilot projects to secure the drain for inspection using this procedure. The use of overpassage of the waste-water, which involves a high level of technical, financial and organizational input and for these reasons is not practiced by the operators surveyed, was also not necessary here. Thanks to the use of ejector technology, the time-window available for draining and camera-based inspection of the culvert was adequate in all three projects.

Conclusion

It is possible to ascertain by way of conclusion that the use of ejectors permits support of the overall culvert-inspection process as follows:

- Cleaning of completely filled culverts using ejectors;
- Water control, in the form of flanging off of the culvert head, for example, possibly combined with the use of ejectors for pumping off and overpassage of the waste-water;
- Use of ejectors positioned at the lowest point in the culvert for drainage of the culvert pipe and
- Culvert inspection by means, for example, of camera-based surveying.

Ejectors can be used as both cleaning nozzles and as pumps in such projects. The ejector can be regarded as a robust and easy-to-handle dual-function (cleaning and pumping) tool which is powered by standard high-pressure cleaning vehicles and can be combined with the components already in use in drain and sewer operation. Ejectors are also used for other applications in which it is necessary to move water, waste-water, sludge and/or coarse depositions.

Results in the Internet

This article provides only a summary of the research results. The complete version of the „Use of ejector technology in culvert cleaning and inspection" research report is available for download the Internet: www.ikt.de

References

[1] Bosseler B., Bennerscheidt C.: Use of ejector technology in culvert cleaning and inspection. IKT- Institute for Underground Infrastructure concluding report, on behalf of the NRW Ministry of the Environment (MUNLV), 2004. Available for download at www.ikt.de

[2] Bosseler, B.; Gronau U.: „Inspection and cleaning of culverts" experience report, IKT – Institute for Underground Infrastructure, 2002

Source: IKT eNewsletter, March 2007

Recovery of heat from waste-water

Supply and return lines to the heat-exchanger

The IKT has performed on behalf of the NRW Ministry of the Environment a study into the conditions under which recovery of heat from waste-water might be technically and economically feasible using currently available technology. These conditions then formed the background for an approximate assessment of the energy- and environmental-policy potentials for the state of North Rhine-Westphalia.

The process of heat-recovery from waste-water

More than 1,200 million m³ of drinking-water (referred to in engineering circles as „potable" water) are consumed every year in the German state of North Rhine-Westphalia. The majority of uses are associated with heating. Waste-water temperatures in the municipal drain and sewer system in NRW, with a total length of 90,000 km, are predominantly between 10° C and 20° C. This waste-water therefore has a thermal potential which might make it interesting for recovery of heat. Waste-water heat recovery systems (WHRSs) are used in order to exploit the heat contained in waste-water for the heating of properties and for provision of hot-water supplies. Heat-exchangers are installed in suitable section of drains and sewers and transmission lines; the overall system is completed by a heat-pump and, where required, a unit-type heat+power cogeneration plant for supply of the energy necessary to drive the heat-pump.

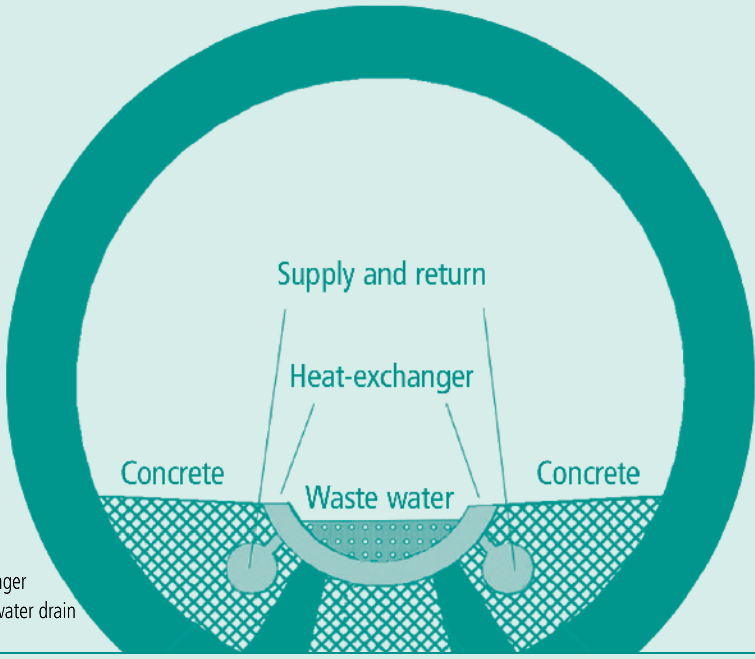
WHRSs are used to supply base-load, and additional heating systems, such as a conventional oil-fired or gas-fired heating boiler, for example, are necessary to cover peak loads. WHRSs can also be used for air-conditioning, however; in this case, the heat-exchange takes place in the reverse direction, i.e., surplus heat from rooms in buildings is transferred to the waste-water.

The effects of heat-exchangers on the drain/sewer system

One important precondition for the exploitation of waste-water heat is that waste-water disposal must not be obstructed. For this reason, the IKT has conducted tests on heat-exchanger elements in order to assess their working reliability, durability and effects on conduit cleaning:

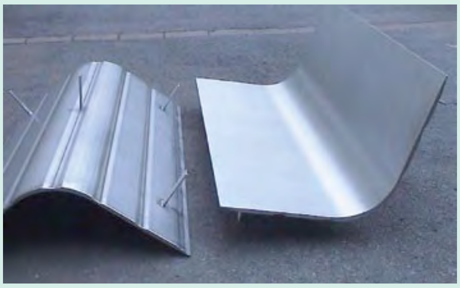
Overview of the IKT test program

	Test	Test criterion/Result
Working reliability	Shearbox	Coefficient of static friction and coefficient of kinetic friction
	In-situ determination of coefficient of kinetic friction	Coefficient of kinetic friction
	Entry	Slipping hazard
Durability	Exposure in accordance with DIN EN 175	Visual inspection and mass losses
	Exposure in accordance with operational loads	Visual inspection
	Darmstadt tipping runner	Abrasion
Conduit cleaning	Abrasion tests with a nozzle-body	Mechanical exposure
	Impact tests	Mechanical exposure
	Hamburg flushing test	Hydrodynamic exposure



Heat-exchanger in a waste-water drain

All the tests were orientated around Rabtherm® system heat-exchangers elements, which the Technische Betriebe Leverkusen (Leverkusen Municipal Engineering Department) has installed in a drain. The heat-exchanger elements consist of stainless steel (Material No. 1.4571), are installed in a dry-weather channel, and are in direct contact with the waste-water.



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

The IKT studies indicated that neither negative effects on tightness and stability, nor any restrictions on durability caused by corrosion processes, need be anticipated. Drain-cleaning operations also cause no negative effects on the durability of heat-exchanger elements.

In the case of working safety, the normal care and normal precautions taken for entry to masonry conduits are, to be on the safe side, appropriate, but also adequate, for entry to stainless-steel heat-exchangers.

Suitability of drain sections for installation of heat-exchangers

There are specific technical requirements which determine the suitability of sections of drain conduit for the installation of heat-exchangers:

- Minimum cross-section > DN 800 (walk-in conduit)
- Average dry-weather flow > 12 to 15 l/s
- Minimum gradient
- Conduit material and condition (in case of retro-installation)
- No restriction on necessary hydraulic reserves (in case of retro-installation)
- Conduits with straightest possible course, with a straight length of up to 200 m
- Accessibility during both construction phase and operation
- Constant minimum temperature for treatment-plant operation

Rabtherm® heat-exchanger elements in a drain (photo: Wallstein Ingenieur GmbH)

The technical requirements are, it is true, on the whole rather numerous and diverse, but it is nonetheless perfectly possible to find locations that fulfill all of these criteria.

Profitability the key economic criterion

Marketing of thermal energy recovered from waste-water will be possible only provided the participating bodies, i.e., the energy-supply utilities, the system operators and property owners, are prepared to enter into a long-term cooperation which will bring economic benefits for all concerned. The time-horizon involved extends to fifty years or more.

System operators (SOs) will have incentives to utilize waste-water heat provided installation and operating costs are completely covered and, in addition, it is possible to achieve a profit.

From the point of view of property owners (POs), the kWh-prices for thermal energy from waste-water must, depending on location and preference, not be greater than market prices for thermal energy from conventional and from renewable heat-supply systems.

Energy-supply utilities (ESUs) which market thermal-energy recovered from waste-water will, ultimately, expect to achieve a net surplus which must meet their profitability criteria. The central economic requirement for recovery of heat from waste-water is located in the profitability of the WHRS: only WHRSs which operate profitably will, ultimately, make it possible to satisfy the requirements of system operators and the ESUs' profit criteria and to supply property owners with thermal energy at competitive prices.

Recovery of heat from waste-water not profitable at present

The purchase and installation of an WHRS and, where necessary, a unit-type cogeneration plant, involve high levels of investment and therefore tie down a large amount of capital. Significant internal costs borne by the system operator must also be added to this calculation. The total investments for an WHRS can easily amount to 500,000 Euro.

System operators' internal costs

Phase	Costs	Relevance
Preparatory	Information costs	high
	Planning costs	high
	Negotiation costs	high
Construction	Material selection	medium
	Installation organization	medium
	Quality Assurance	high
Operational	Capital costs	very high
	Inspection/cleaning, miscellaneous	low
	Success checking	low
Decommissioning/Disposal	Dismantling/disposal	low
	Refurbishing	low

In addition, continuous running costs, consisting essentially of operating costs (energy, servicing and maintenance, premises costs, insurance costs, etc.), depreciation and interest, must also be taken into account.

On an overall view, the recovery of heat from waste-water does not, at present, exhibit the profitability which would be necessary to permit it to assume a relevant position on the market. It must also be noted that potential sales-related (market) risks across the installation's productive life of some fifty years would need to be borne by the WHRS operators and, possibly, also by the participating drain-system operators.

Orientational points for optimization of profitability

Profitability can, in principle, be increased by reducing the amount of capital tied down, by reducing costs and/or by increasing the income generated. Investment levels and continuous costs (depreciation) are lower if WHRSs are installed in the context of the construction of new drain systems or of rehabilitation projects.

Proceeds from operation can be increased if WHRSs are also used for air-conditioning of properties. Since costs per kWh decrease as the size of the WHRS rises, only properties with large requirements for heat should be supplied using WHRSs.

The politicians will decide

The system for recovery of heat in waste-water drain/sewer systems studied by the IKT is entirely operable from a technical viewpoint. Heat-recovery from waste-water is undoubtedly feasible under the preconditions discussed above (minimum cross-section, dry-weather flow, etc.).

It is, however, nonetheless necessary to view the economic rationality of recovery of heat from waste-water with great skepticism. WHRSs cannot be operated profitably at present, and voluntary cooperation projects between the necessary participants are not likely. Entry to the market is possible at the present time only with state subsidies.

The example of the Leverkusen WHRS illustrates that the facility, despite favourable boundary conditions (construction of a new drain system and new properties, proximity to energy purchasers), would not have been constructed without state financial support. And, despite far-reaching state subsidization, Technische Betriebe Leverkusen ultimately decided against construction of the system. Only with the support of Dortmund's HEC energy-supplier was the installation finally approved and built. The conclusion to be drawn is that, ultimately, it is the politicians who can set the path for or against the use of this technology, with their decisions concerning subsidies.

Source: IKT eNewsletter, September 2005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Manhole Coating: An Alternative Renovation Method?

Manhole coated with polyurethane

For the renovation of manholes, coating methods are considered a competitive alternative to the renewal of the manhole. But are they really an alternative? So far there has hardly been evidence regarding limitations of use, influences on quality and the durability of the methods offered. The IKT has lightened the dark: in an extensive practical survey 42 manhole coatings were monitored and investigated at twelve sewage network operators.

Renovation, but how?

Besides the renewal of the manhole lining- and coating methods can be employed for the renovation of large-area damages or leakage. A specific pressure to act is apparent for operators in North Rhine Westphalia (Germany): here the *Selbstüberwachungsverordnung Kanal* (SüwV Kan) (self-monitoring regulations for sewer systems) require the inspection and, if necessary, the rehabilitation of manholes. According to estimations by public sewage network operators, around twelve per cent of the approximately ten million manholes in Germany are basically suitable for rehabilitation with the coating method. The resulting possible market volume for coating methods of around 2.7 billion Euro is immense! Until today, however, there have been large uncertainties regarding the limitations of use of the offered method and the durability of the results of the renovation.

The Quality Components

The IKT chose a very practically-oriented procedure to find out the essential influences on quality when carrying out coating measures. At the same time they intended to sound out the possibilities or limits of use of each methods.

During the two years of the project the following working program was completed:

Grout coating in the spray lining process

Polyurethane coating in the gunite lining process

Manhole coated with mortar

1. On-site Measures

42 coating measures in the drainage networks of altogether twelve network operators were monitored. Extensive quality test were carried out over a period of several months. Grout coatings and coatings of polyurethane were used by considering all cleaning- and application methods that are relevant for the market. All renovations were carried out by specialty firms that had only received instructions regarding the coating material and application method. Comments on the renovation procedure were deliberately not made in order to be able to identify the routine working processes, the actual quality of the renovation as well as possible sources of errors and improvement potentials under realistic circumstances.

Figure left: Documentation of the conditions on the construction site and the renovation
Figure right: Quality check of the renovations carried out

Manhole Coating

2. Laboratory Experiments

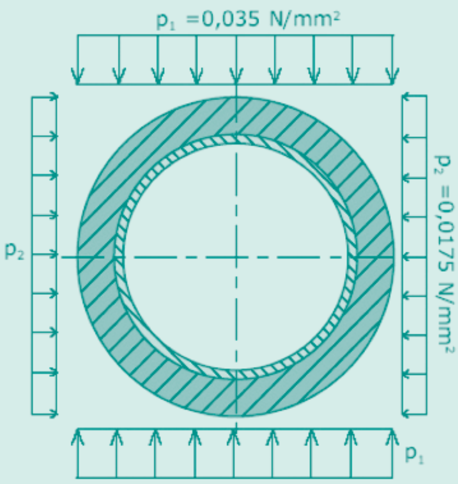
To complement these on-site measures, experiments were carried out in the IKT-laboratories and test facilities. In this way, for instance, the effects of intensive traffic loads on a coated manhole could be simulated or the bonding behaviour of coatings on water-saturated concrete surfaces could be investigated further.

Dynamic load of a coated manhole

Water saturation of manhole elements

3. Special Questions

Further questions raised from the results of the investigations and the laboratory experiments: What are the minimum adhesion tensile strengths of coating? What are the effects of alternative pre-treatment techniques? How does the external climate influence the hardening of grout coatings? How well can the transition to other materials can be created in the joint areas? These questions were followed in additional investigations.



Load case for the numeric calculations of the minimum adhesion tensile strength

Investigation of alternative pre-treatment techniques

Manhole Coating: an alternative! But...

The results of the research project show: the coating methods analysed can basically be helpful to recover the functional capability of brick-built and concrete manholes. Especially with difficult geometries and numerous inflows renovating manholes by coating seems to be an alternative to the new construction of the manhole.

The quality of the renovation, however, was low in the majority of the analysed cases: in 16 of the 26 grout coatings that were analysed visual lacks such as cracks, hollow spots, imperfections or leaks were registered. Only in seven grout coatings an adhesive bond to the old manhole wall could be measured that met the requirements of the relevant regulations. Especially grout coatings in concrete manholes showed a very low bond to the subsurface.

Also among the polyurethane coatings nine of the 16 analysed cases showed visual lacks such as hollow spots, bubbles or imperfections. In twelve cases a sufficient adhesive bond to the subsurface could be found. Only very wet surfaces seemed to cause problems.

Inaccurate application of the coating, in particular, could be identified as a main reason for the poor renovation quality. Furthermore, the preparation of the subsurface was insufficient in many cases. Generally, the preliminary cleaning of the manhole with water pressure, which is very common today, only seems to be suitable to a limited extent for preparing the coating measure. It can be recorded that the current measures for quality assurance – especially when looking at the usual practice – urgently need improvement. This is why IKT – starting from the experiences made – develops help guidelines for quality assurance, which can be used by the sewage network operators for tendering, construction monitoring and final acceptance of renovation measures using coating methods.

High-pressure water cleaning of a manhole wall with a hand lance

Material Behaviour and Application Limits:

Present Cleaning Methods hardly suitable

To keep a sustainable subsurface and the preconditions for a good bond of the coating, first of all dirt, coverings and glaze as well as damaged material have to be removed from the manhole wall. For this purpose, usually high-pressure water cleaning is used.

High-pressure water cleaning of a manhole wall with a rotating cleaning nozzle

In the IKT experiments showed that this method is only scarcely suitable: often coverings and glazes could not be removed from bricks. Also cleaning out brickwork joints in an adequate depth nearly always proved to be difficult. In concrete manholes there is often the problem that the subsurface cannot be roughened adequately to ensure a sufficient hold of the coating grout with the surface.

As a test some manholes were cleaned with high water pressure by mixing in sand. The results of the cleaning were clearly better. However, the working conditions for the executive technician were catastrophic: not only was he forced to protect himself against the rebound of water, but in addition against the rebound of sand.

> Here the industry seems to be in demand: a new cleaning device, similar to the already available rotating cleaning nozzle, is needed in order to apply water and sand mechanically to the manhole wall.

Automatic Application is not necessarily an Advantage

Pre-coating of a brick-built wall with severe joint corrosion

Brick-built manholes with strong joint corrosion and concrete manholes with advanced concrete corrosion have a very uneven wall surface. Before these manholes can be coated by spray lining, the surface needs to be flattened manually with a pre-coating of mineral mortar first.

Completely pre-coated brick-built manhole

These manual works often comprise a major part of the total work effort. This pre-coating also presents – depending on the layer thickness – a complete coating of the manhole. By the subsequent mechanical application of a main coating, the compound strength of the pre-coating cannot be increased any further.

> In these cases the question has to be asked why the spray lining method has to be applied for renovation additionally after all and why the entire coating thickness is not applied manually in the first place?

Polyurethane: Big Differences between the Products

Bubbles in a polyurethane coating with high surface moisture

The laboratory experiments clearly show big differences between the single products offered on the market. Especially the sensitivity towards moisture differs: while one of the PU-products analysed reacted to a high level of moisture, another PU-product showed no visually noticeable reactions.

Flawless polyurethane coating also with a high surface moisture level

> Polyurethane is not like polyurethane.

Manhole Coating

Polyurethane: Caution when coating very moist Brick-built Manholes

All polyurethane products analysed did not adhere well on moist surfaces. Especially on PU-coatings which were applied to soaked brickwork, the IKT testers measured only a slight bond with the surface. In exceptional cases also debonding was observed.

Drying of a manhole in the run-up to a polyurethane coating

Often renovation contractors use mobile heating equipment to dry the brickwork before it is coated. But even after drying, in some cases the surface moisture was still too high.

> Thus, the use of polyurethane for coating very moist brick-built manholes seems not recommendable.

Requirements of Mortar vs. Requirements of Polyurethane

Generally, there is a difference between the requirements of a (pre-coating) mortar and those of a polyurethane. While, if possible, the mortar should be kept rather moist during hardening, for coating with polyurethane a dry environment is an advantage.

This different requirements can become critical if both materials are used in combination. This is the case, for example, if a manhole is pre-coated with mortar to even the surface and is to be coated with polyurethane afterwards. To achieve the lowest possible moisture of the surface for applying the polyurethane here coating contractors often like to use mobile heating guns, by means of which the manhole – and thus the grout layer – is dried.

Using these heating devices can influence the hardening since it forms the subsurface for the polyurethane coating.

> Thus, our recommendation: wait with the polyurethane coating until the mineral pre-coating has enough residual moisture. Do not use mobile heating equipment for drying.

Preparation of the Renovation

Clever Inspection before the Acceptance of bid!

Damaged manhole

In the phase of preparing the renovation the manhole to be renovated should be visually inspected in detail. Ideally, the inspection should be carried out with a high level of groundwater in order to be able to notice leakage in the manhole body.

Leaking annular joint inside a manhole of concrete components

Here, also the condition of the vicinal sections as well as the other branches in the manhole wall are to be documented. If damages or leaks are noticeable in the vicinal sections, in the ideal case the renovation of the manhole should be integrated in the rehabilitation of the entire system.

Where are the Damages?

Leakage in the channel in the area of the discharge

Nearly all manholes showed severe damage in the lower area of the manhole body, in many cases the berms, channels and connections to the outgoing sewers also needed renovation.

Transition area of a rectangular brick-built manhole/round concrete cone with horizontal ledges in the manhole wall.

If branches were integrated in the wall, they were leaking or damaged in nearly all cases. In the transition area of brickwork to concrete often leakage and transverse displacement were found, which can complicate a renovation with the coating method.

Plan Preparatory Works!

Damaged branches inside the manhole wall are to be renovated before starting the coating. Step irons should be demounted before coating. After the coating is completed, the use of a ladder is particularly recommended as then the body of the coating has only to be broken through at a few spots.

Before coating, in many cases the manhole wall needs to be sealed. In manholes of pre-fabricated concrete components good results can be achieved with injections like polyurethane resins, for example. Sealing by means of injection in brick-built manholes is more laborious. If there is no in-situ groundwater that pushes, here especially quickly setting repair grout is helpful.

Looking at a couple of essential points during renovation can increase the probability of a successful renovation enormously:

Control the tidiness of the manhole wall.

Formation of spray shadows next to a step iron caused by grout coating with spray lining

Injection material entering through leaks inside an annular joint of a concrete manhole

Dirt residues on the wall after cleaning

With grout coatings by spray lining as well as with polyurethane coatings by the gunite lining process, spray shadows develop at the step rings. In addition, these areas have to be prepared manually or have to be re-worked.

In brick-built manholes and manholes of pre-fabricated concrete components with corrosion usually a comprehensive mechanical preparation of the surface is necessary. In manholes consisting of prefabricated concrete components without corrosion preparatory works are normally limited to annular joints.

Sealing of a brick-built manhole with filling jointing grout

In brick-built manholes with joint corrosion normally laminar pre-coatings with mineral grout are necessary before the coating is applied mechanically (grout and polyurethane).

Construction monitoring

Generally, the following applies: the present practice under the special conditions in manholes seems to have a strong impact on the results of the renovation. Here in particular:

- procedural weaknesses in the preparation of the surface,
- manufacturers not meeting the requirements and the essential regulations during the entire renovation process and
- the lacking control of the rehabilitation success

are to be mentioned.

Manual processing on site, slow hardening of the material and the high requirements of the reworking are becoming more serious when using mortars. A more intense construction supervision compared to present practice is definitely recommendable!

In practice, insufficient preparatory cleaning can occur. This is why after completed cleaning dirt residues can be found on parts of the wall. A finishing check of the manhole wall before applying the coating is not carried out in all cases.

Applying the grout onto a „dirty'" wall

Thus, before applying the coating, a detailed inspection of the cleaned manhole wall should be carried out to be able to notice dirt residues, coverings or a too low material removal and to introduce further measures if necessary.

Manhole Coating

Check the material used

In many cases inadequate materials, especially for pre-coating, are used. For example, for concrete manholes with severe corrosion only grout products are suitable, which were developed especially for the use in very aggressive sewage.

Green-black colouring of the pre-coating inside a manhole with strong impact of sulphuric acid

Thus, check the materials used by the contractors whether they are really suitable for the application.

Mortar: urge the observation of manufacturer requirements

To improve the mortar's processing characteristics for manual application, in practice the requirements by the manufacturers are interpreted in a very creative way. For example, it could be possible that slightly hardened mortar is again mixed with water and is used for coating.

Thus, already in your call for tenders point at the requirements of the manufacturers and the observation of processing regulations and randomly check the construction works during the building process.

Finishing treatment is highly important

The moisture level of the surface before applying the mortar as well as the drying of the mortar have strong impact on the tensions occurring in the mortar coating as well as in the environment of the connection joint. These tensions can lead to debonding and to cracks in the coating. For this reason care should be taken of a moist surface, of keeping the mortar moist during application and especially of preventing early drying during the hardening process.

In addition, if, while applying the coating, the single, already dried layers are not roughened before applying a new layer, a bad result of the renovation can be the consequence. Principally, the grout coating is to be protected from direct insolation especially in the cone area.
By applying a finishing treatment medium to

A finishing treatment medium can be of great help

the mortar coating directly after the renovation works, it seems to be possible to prevent too quick drying of the mortar. Sealing the manhole cover with an awning to prevent incoming air does not seem to cause great advantages as a single measure. For polyurethane coatings comprehensive finishing treatment does not seem to be necessary. Here it is advisable, however, to inspect the entire coating cover visually in detail after applying the coating. So imperfections in the coating can be registered and can be removes immediately.

Sealing the manhole cover simply does not suffice

Polyurethane: check coating immediately after application

finishing treatment of a polyurethane coating

Acceptance of the Construction

Principally, it can be observed that the measures suggested in guidelines and progress reports are only suitable to a limited extent for testing the quality of a manhole coating in a sustainable way and especially with adequate effort. The following measures for quality checks have turned out to be reasonable:

Approval of the construction after several months

Weaknesses in the polyurethane coatings normally showed directly after applying the coating or at the latest after an ascent of the groundwater level. In many grout coatings numerous deficiencies could only be observed during an inspection several months after the coating measure. This might be due to the fact that the tensions in grout coatings, which are responsible for the formation of cracks or debonding of the coating, only develop after a few days or weeks from a mathematical point of view.

Cracks often become obvious after a couple of months

Therefore, it is advisable to carry out the construction measure after a couple of months and ideally with higher groundwater levels.

Areas with bad bonding can be noticed after an ascend of groundwater at the latest

A detailed visual inspection is an adequate measure here

A detailed visual inspection under high groundwater levels including tapping the coating is particularly suitable for an acceptance of manhole coating measures. Lacks in quality such as cracks and leaks can usually be noticed rather well: due to the typical sound when tapping the coating also hollow spots behind the coating can be registered.

A detailed visual inspection is great help when assessing the quality of a coating

However, great care should be taken of the fact that the condition of the coating is acquired during a visual inspection of the entire manhole construction. It should include the connection area, channels and step irons and should be documented by photos. The simple examination through the opened manhole cover does not suffice!

leaktightness testing does often not suffice

A water tightness test inside the manhole does not always give reliable statements with regards to the success of a coating measure.

A leaktightness test of a manhole does often not suffice to assess the quality of a coating measure

Often the test results cannot be used due to circular seepage in the area of sealing bubbles, for instance. The costs are often out of all proportions to the usage. In extreme cases (e.g. strong volume stream, large cross sections, corroded sewers) the costs for the final leaktightness test can exceed the costs of the actual renovation measure.

Only if also the invert area including the channel as well as the connecting sewer sections were rehabilitated, a test with water can lead to a successful result in individual cases. Generally, then a water leaktightness test according to DWA-M 143, Part 6 seems to be reasonable in combination with a comprehensive visual inspection of the upper manhole body.

Question the adhesion tensile test

As a criterion of acceptance, in general, the current minimum demands on adhesive tensile strengths of the coatings, influenced by the requirements of structural engineering and bridge building, as well as the importance of adhesion tensile tests are to be questioned. Numeric analyses showed that adhesive tensile stresses in grout coatings, developing under these conditions in a manhole, are below the requirements of the essential guidelines.

Mortar: adhesion tensile test of a coating

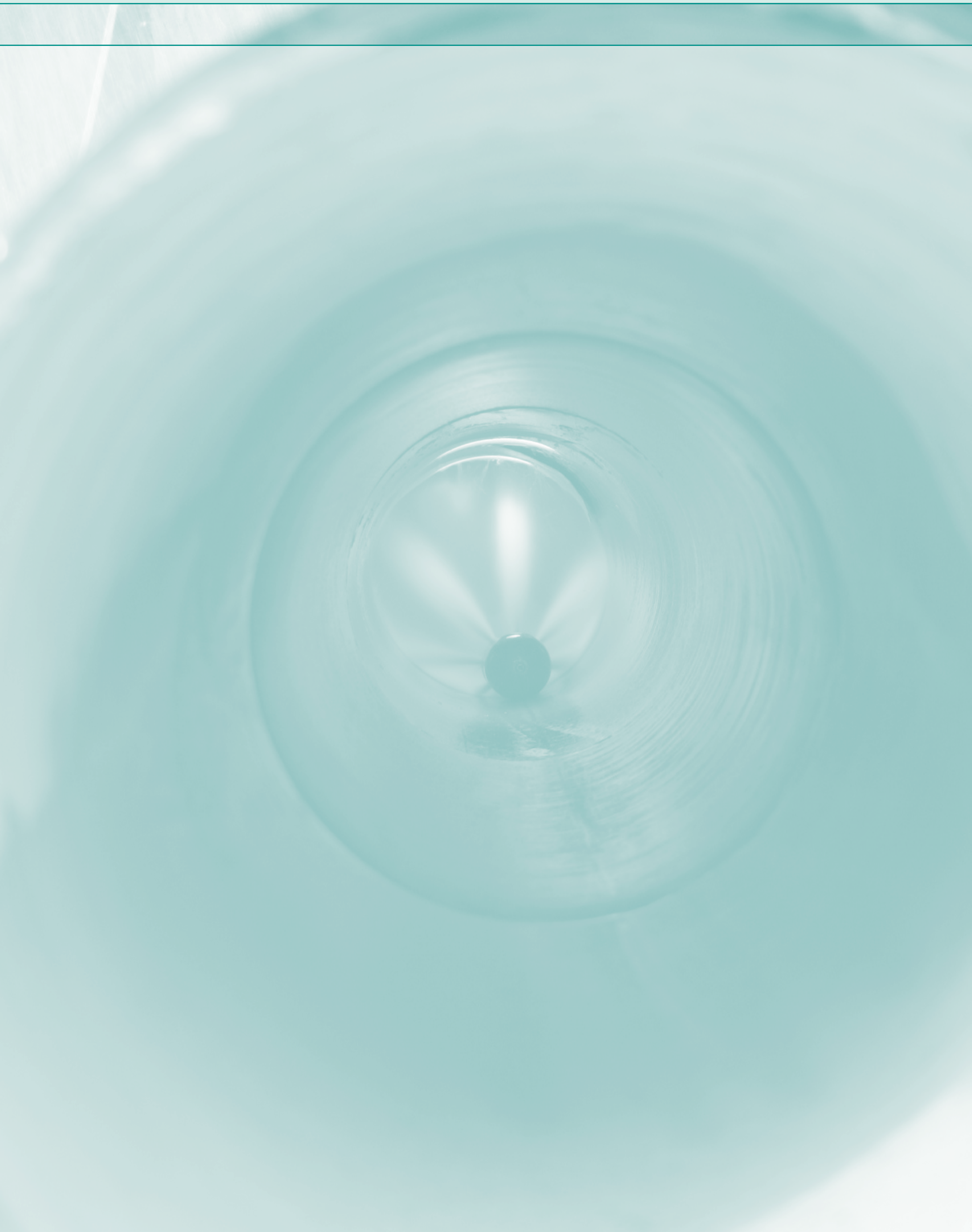
And although in many cases the demands on the adhesive tensile strength were not fulfilled, a loosening of the coating could only be noticed in single cases. In the cases in which extremely low adhesion tensile values of only 0 N/mm² to 0.2 N/mm² were measured in the final adhesion tensile test, the IKT testers had already noticed cracks in the coating and hollow spots by tapping the coating.

Against this background, the result of an adhesion tensile test should only be considered an additional hint on the renovation quality and the visual inspection including tapping the coating should be focussed on.

To be continued

As the article shows, basic findings regarding the influence of quality and limits of application of coating measures are now available. In the present research project „manholes – monitoring, testing and renovation" further questions are to be answered. It aims at the comprehensive analysis of the entire manhole body and the corresponding operation processes. In laboratory and in-situ applications various renovation processes are analysed in comparison.

Sources: IKT-eNewsletter April to September 2005



Jetting damage risk: Product tests help to avoid surprises

Which power of cleaning can be maximally employed without causing damage to the sewer, significantly depends on the pipe and rehabilitation product. Therefore, the question of high pressure jetting durability is an important aspect of purchase decision. Product tests offer a possibility to recognize the risks of subsequent jetting damages in operation at an early stage. The IKT has already analysed diverse pipe products and rehabilitation systems and has access to up-to-date research results on the aggressiveness of HP-nozzles.

Risk of HP-cleaning – aggressive HP-streams with high dissolving force and accelerated solid bodies stress the pipe walls

How reliable is a product?

IKT conducts practical jetting tests on pipe and rehabilitation materials. The manufacturers as well are interested in the reliability which their product can offer to the customer, since the requirements for flush durability of pipe systems have constantly grown. In the meantime, modern high-performance high pressure cleaning crafts provide high nozzle pressures with simultaneously high rate of delivery for sewer cleaning. Moreover, network sections are often intensively cleaned over 50 times under high pressure during their operation time.

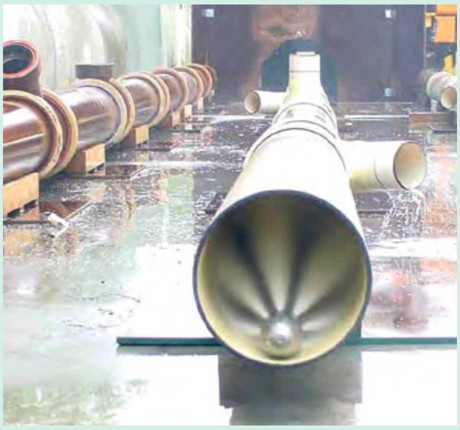
Product tests – example: Sewer jetting test Aggressiveness of high pressure nozzles

The development of test concepts and measurement of results requires knowledge of cleaning processes and nozzles, since stressing of component surfaces seriously depends on the cleaning situation and the properties of the nozzle; and the choice of nozzles currently available on the market is wide. In the IKT Market Research on High Pressure Nozzles (www.ikt.de), over 1000 nozzles from 12 manufacturers can be found. This alone proves that not every way of cleaning is the same. For this reason, IKT developed a measurement system for recording of HP-stream properties. At the same time, the distribution of the stream pressure – especially the peak pressure and the stream impact area – measured using pressure measurement foils. These characteristics are important in order to describe the dissolving force and the aggressiveness of high pressure streams (comp. table 1).

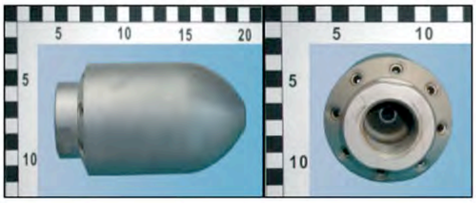
Left: jetting test on a tube liner

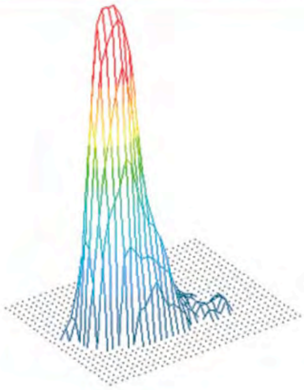
Middle: 50 cleaning cycles at nozzle pressure of 120 bar

Below: Additional test: prolonged punctual overstressing for 3 min



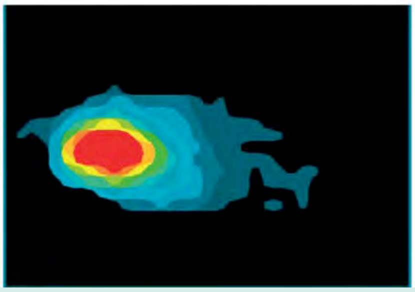
nozzle D1 (8x30°)





8 holes
∅ 2,8 mm, steel
angle: 18°
angle: 30°

limiting conditions			measured variables		
	P	100 [bar]		A	621 [mm_]
	Q_S	36,9 [l/min]		P_{max}	6,1 [bar]



In order to provide for the repeatability or test stress, the stress parameters nozzle pressure and rate of delivery of the pump have to be measured. IKT employs a magnetic inductive flow measurement device and a pressure sensor for this goal. If a risk of flush damage is recognized in an already manufactured product, simple possibilities of cleaning process adjustment for sparing cleaning offer themselves. Thus the cleaning process can be customised for the particular situation if needed by alteration of the choice and application of cleaning instruments.

Metrological observation of nozzle pressure and flow rate for exact assessment of test stress

Following basical points offer themselves in this case:

- Sewer bearings with particular risks for the network substance should already be identified at the stage of planning. This is especially relevant for the ranges which already showed vulnerability for the HP-cleaning at TV inspection, e.g. fragile damaged spots, skews and protruding connection pieces.
- The goal of the cleaning should be regarded as basis of nozzle choice, meaning the question if the nozzle requires a dissolving effect beside conveyance capacity. If only the transportation ability is important, a nozzle with flat stream angle (under 20°) or a nozzle with ejector effect should be employed when possible. If aggressive nozzles are used, a random test on singular bearings (parallel TV inspection) should be performed to examine the effect of employed nozzle systems on pipes, sockets and connections under the customary cleaning conditions.
- Undesirable material alterations can often be avoided by simple increase of stream distance to pipe wall, e.g. by employment of a nozzle sliding carriage.

Common cleaning tasks can usually be reliably accomplished with pressures under 120 bar. Regular controlling allows to determine and evaluate the effect of chosen diameter of the nozzles, pump capacity and hose lengths on the rate of delivery and nozzle pressure.

Considerable risks for the network substance can be dramatically decreased even by simple measures:

- On letting the nozzles into the sewer, impacts on the shaft or pipe walls should be avoided.
- The nozzle speed should be monitored. The no-load operation must be prevented in any case.

- Continous monitoring of pump pressures and corresponding motor rotation speed allows to recognise irregularities. In this way, a pressure increase can point at blockage of the nozzles and thus the dangers of excessively aggressive HP-streams. Low pump pressures point at worn out nozzles with deficient dissolving effect.
- The pump pressure should be lowered possibly slowly to prevent the nozzle body from falling onto the pipe wall.
- It is in any case advisable to keep an eye on the flush water to recognise possible breakage of already existent sewer damages.

Source: IKT-ERGEBNISSE 2002-2005

Causes, Tests and Prevention

Why do tree roots penetrate pipes - and not only where the pipe is damaged? Root damage to the pipe connections of duly laid, intact pipes causes millions of damages per year. Engineers and biologists prospected the reasons together. Their results are already turning past theories topsy-turvy and have consequences for laying pipes.

Sewers are a rather inconspicuous property of cities and municipalities. But there are few things so important for the community. This becomes particularly obvious, when sewers do not work properly. A frequent cause are roots growing into pipes. While one can resort to bottled mineral water instead of drinking water, help out with aggregates in the case of electrical current and simply do without television occasionally, a defective sewage system is always an acute problem, that has to be solved quickly.

We have investigated why roots represent a problem for piping systems at all in a co-operation project of the Chair for Systematic Botany and the Botanical Garden of the Ruhr-University with the IKT - Institute for Underground Infrastructure. Concepts to avoid this damage are to be developed, based on the accurate knowledge of what happens when roots penetrate. Sound precautions are particularly important, since it usually takes more than 10 years from pipe laying to the occurrence of damage and pipes should last for a long time (service life: 50 to 100 years).

Biologists and underground engineers seem to be „natural enemies“ in this respect, because one group argues, that nothing can happen, if the pipes are „decently“ laid, while the other considers wood as an aggressive destroyer of the marvel of their engineering art. A biology student, who jobbed in underground engineering and returned to his academic roots with this problem, made the contact between both worlds.

Biologists and engineers both initially assumed, that the roots find the pipe, because small amounts of water escape through leaks: The roots grow along moisture gradients (soil area with increasing water saturation) towards the pipe, since the primary function of the roots is water absorption; they then penetrate into the pipe through the leaking locations - because there is even more water there. Robot cameras, driven through the pipes, show us nowadays from close up, what really is happening in the pipe. How the root grows towards the pipe connection before penetrating can however only be recognised, if a defective pipe area is carefully excavated (s. Figure 1).

Figure 1: Excavating a pipe penetrated by roots calls an archaeological approach to mind

Root penetration in sewers

The driving videos already show amazing things: The roots usually hang into the pipe from above and end just over the water level. (s. Figure 2A and B)

Fresh, well growing roots also died within days to weeks in different waste water samples in control experiments with rooted cuttings.

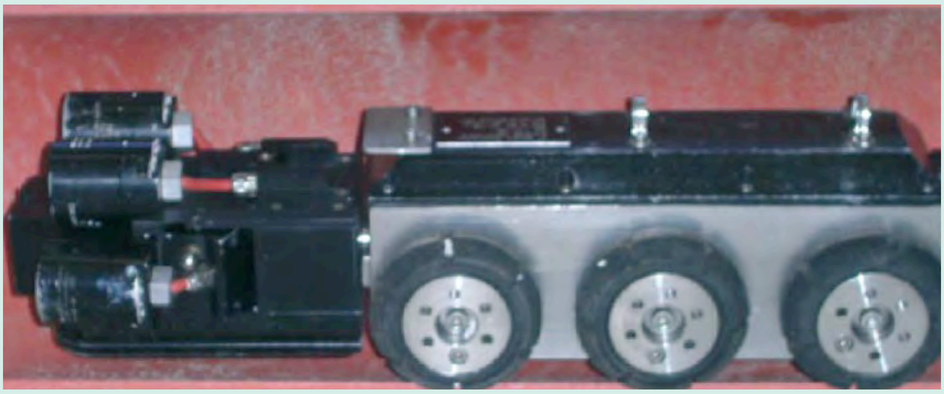


Figure 2: The robot camera (A) drives through the pipe system and „views" root damage (B) from close up.

They do not reach their assumed goal - the water. We therefore examined, what happens during root penetration into the pipe in a project promoted by the Department of the Environment of the province North-Rhine/Westphalia. We then experimentally examined the hypotheses gained from the excavations as a next step. The excavations also resulted in surprising results: Waste water and rain water conduits differ from each other in root growth (s. Figure 3 and Figure 4). The roots always penetrate the pipe above the medium water level in waste water conduits, where they immediately branch out strongly. The roots parts immersed in the waste water were strongly damaged or had died. They erode in the water and form a plug, which then does not dip or only slightly dips into the water.

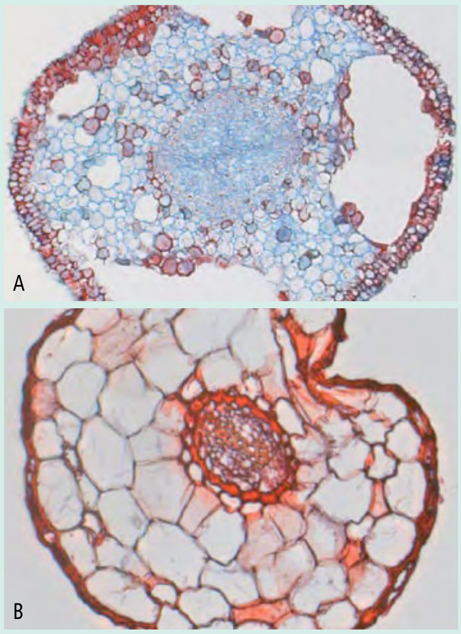
The colour of the immersed roots already indicates that they had died, which was then confirmed by the histological analysis. (s. Figure 5 A and B)

The water from sewers will probably not be the goal of root growth, if it kills the roots so quickly. The penetration of the roots into the pipe above the water level also contrasts the idea that leaking water is the primary cause of damage. The moisture of the few water drops leaving leaking pipes is not sufficient for building up an adequate moisture gradient, since birches or populars need up to 300 litres water per day. Likewise because the root hardly branches out outside the pipe, which is normally the case in moisture gradients. The root also penetrates the side of the pipe connection in rain water conduits but meter-long root system develop every now and then on the conduit base (s. Figure 4). The roots are in a much better condition than in waste water conduit, although there are many dead roots there as well. However these show no decomposition characteristics, but have probably just simply dried. Pure rain water conduits dry out faster than soil in summer during long fair weather periods. Sufficient water is also present outside the pipe during rain. The first excavations suggested that the roots do not grow towards leaking pipes and then into them due to loss of water. But then what is the reason for the root growth? We chose two approaches in our project: IKT researchers measured, which forces roots can actively muster. Pavements and tar coatings lifted by roots are not very informative in this respect, since thermal movements probably create the space, with in-grown roots only maintain.

Figure 3: The roots penetrate the pipe above the medium water level in waste water conduits and immediately branch out strongly.

Figure 4: The roots develop meter-long root trails on the base of rain water conduits.

Figure 5: A section of a root immersed in waste water makes the damage visible under the microscope (A). Comparison: Cross-section of a healthy root (B)



Measuring the root force

The physiological characteristics suggest, that some roots can apply pressures of approximately 6 bar. This was approved by a special test assembly at IKT. Root forces of 5.9 bar were be measured by a pressure sensitive film (s. Figure 6). Thereby the engineers measured in a first step the pressure of roots growing in a continuously decreasing growth space made of plaster (s. Figure 7). In a second step they looked at the pipes. Using similar pressure sensitive films they messured the surface pressure of different joints while increasing the shear load up to a limit required by standards (s. Figure 8 as an example). The comparision of both results leads to the statement whether the pressure applied by roots can push the seal aside.

Figure 6: Test assembly for the determination of the root force: How far and with which force can the roots penetrate into an ever closer pressure sensitive film?

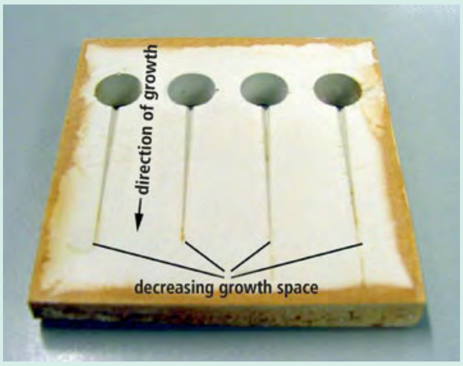


Figure 7: Pressure plate made of plaster

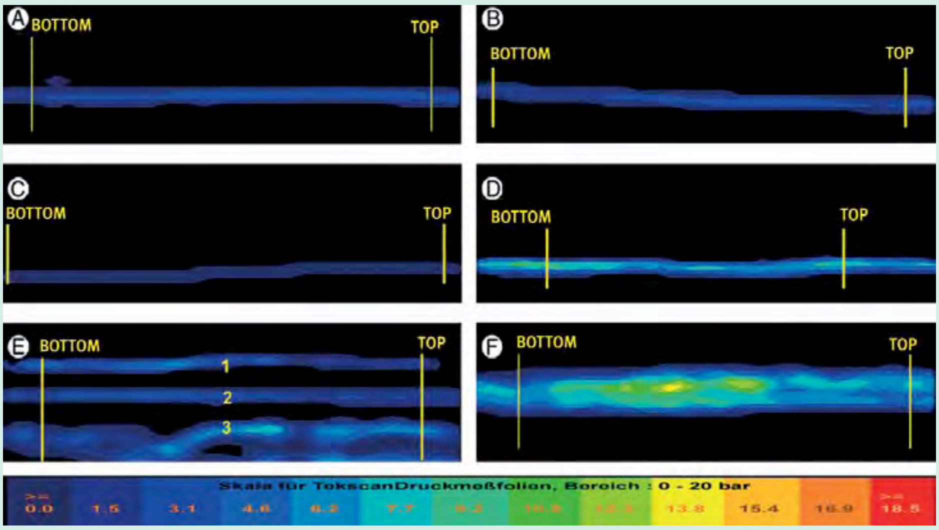


Figure 8: Measuring the changing of pressure and pressure area under shear-load using pressure sensitive films [1] (Tyton connection with a diameter of 150 mm). A Without load: Relevant surface pressure of 6.6 bar. B 1. Step: shear-load of 971 N: Relevant surface pressure of 5.5 bar. C 2. Step: shear-load of 1942 N. Relevant surface pressure of 3.1 bar. D 3. Step: Shear-load of 2914 N. Relevant surface pressure of 3.1 bar. E 4. Step: Shear-load of 4500 N. Relevant surface pressure of 2.6 bar. F After1,5 hours, under a shear-load of 4500 N: No significant change in comparison to E.

At the Ruhr University it was examined how a root in the soil „decides“, where to grow. It is well-known that root tips perceive gravity by starch grains, because they sink downwards in the cell. Moisture, temperature and nutrient gradients are probably also important for directional growth. But how does a root find its way around an obstacle, e.g. a stone? There must still be other reasons for this growth, since roots grow into cellars through foundations or through green roofs into rooms, where it is neither damper nor richer in nutrients. Little is known about the behaviour of the roots in soil, since physiological investigations are usually carried out on radicles and in nutritive liquids for practical reasons.

Understanding these processes requires the knowledge of the root tip structure (s. Figure 9 and Figure 10): The root tip is a short multifunction organ. Its root cap (Calyptra) protects the growth zone and consists of desintegrating cells. The initial zone is located below the cap.

The longitudinal growth starts from here and new calyptra cells are also formed. The root hair zone follows the growth and elongation zone. Root hairs are usually short lived, their function is seen as surface enlargement for waterabsorbtion. The so called endodermis is an important root layer. Water is pumped into the conducting tissue of the root in the endodermis cells using energy. Energy is required, because the water absorption must take place against the concentration gradient of ions such as sodium or chloride; otherwise salt crusts would rapidly develop on the leaves, where large amounts of water evaporate. Oxygen must be present or transported to the root, where no photosynthesis takes place, since energy expenditure always means oxygen consumption.

The gradient is actively built up by the endodermis in the root. Surface enlargements take place above all, where the gradient is built up, where ever physiological processes play a role. The root hair surface enlargement is relatively insignificant in this respect. Surface enlargement seems to be

Figure 9: Build-up of the root tip

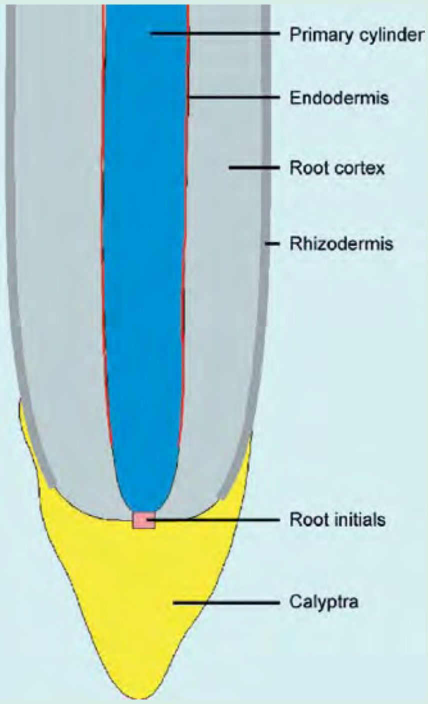
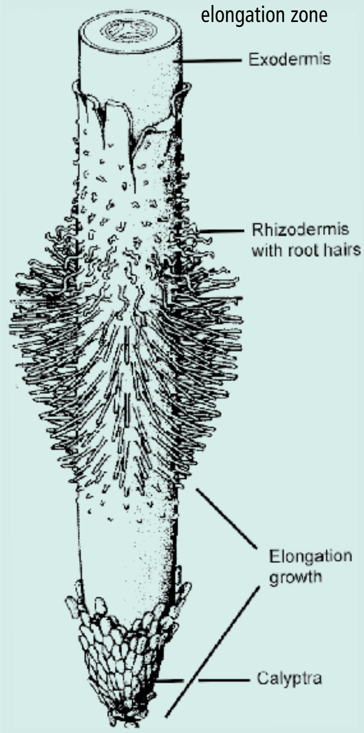


Figure 10: The root hair zone follows the growth and elongation zone



irrelevant in respect to roothairs as the gradient is not performed there. An leek plant forms e.g. over 50 cm long roots, which however do not branch and only exhibit root hairs at the tip. If root hairs would primarily serve for water absorption, then the overall root length increase of the leek plant would be in vain, since the absorbing surface - the root hair zone - only shifts, but does not increase. It seems obvious, that roothairs are predominantly formed for anchoring purposes. They function quasi as counter bearings, when the root tip is pressed into the substrate.

Soil density determines direction of root growth

The root cap has not only a passive protective function during this process. The cells are pressed forwards away from the initials and form a channel, into which the root grows. The root cap is therefore the drilling head of the root. But the root cap consists of dying, isolated cells, particularly within the foremost area. How does this drill find its direction? The calyptra cells are passively pressed forward by cells located farther back. The soil density (substrate) determines the direction of root growth, just as further groups move to where there is room in a football stadium crowd: The roots always grow into the less dense substrate at a density border.

The drilling head can work against this growth trend, although extremely limited, by unilateral growth behind the initial zone. The growth direction is thereby the result of at least two factors - the force of gravity and the substrate density. A dominating factor can sometimes define the growth direction. This happens e.g. if the root reaches a pipe connection. A cavity, which cannot be filled out and compressed, always results prior to the seal due to its construction (s. Figure 11). The root grows into this cavity once it has found it and can only get out again, when this pipe connection area is filled with root mass as densely as or more dense than the surroundings. Whether it then grows into the surrounding substrate or into the pipe, is probably just by chance. But if the root grows around the pipe within the joint and enlarges afterwards due to secondary thickening growth, it blocks its way back to the substrate. It then pushes the rubber seal aside and penetrates inside of the pipe (s. Figure 12).

To achieve better understanding of the relevant cavities between the spigot and the socket of a joint the engineers sliced several connection. They messured the size of the cavities (no substrate density) that could give roots a place to grow (s. Figure 13).

When roots „block“ their own way back.

The pipe connections excavated so far show, that a root can grow in the pipe connection for more than two years, before it grows through the seal into the pipe. We have proven this using the annual rings, which are also formed in roots. These findings confirm our hypothesis, that „Density traps“ - like the pipe connection cavity – lead the roots to the pipe connections. These results have been confirmed in model experiments. Growth areas in the substrate, e.g. pore spaces between the bedding and/or filling material seem to be primarily relevant for forming „Density traps“ and not primarily the degree of mechanical compression, as it is achieved with vibrating rollers or plates. The question of the pipe root fastness must therefore also be regarded in connection with bedding and backfilling. A further important starting point results from the root physiology. Since active transportation processes are carried out in the endodermis, oxygen is used there. Underground plant parts, which exhibit such transportation processes and live under oxygen deficiency, often form complicated aerification tissues. This is however not the case

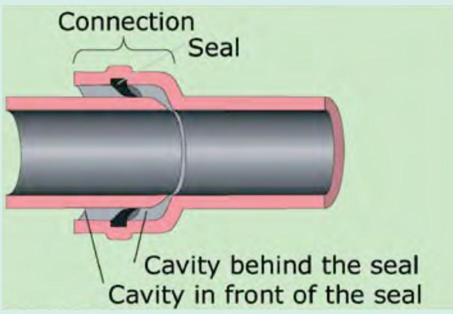


Figure 11: The pipe connection seal is a „Density trap“ for the root.

Figure 12: The root has „blocked“ its way back into the soil itself – the only way out is to push forwards. The root tip pushes the seal aside and grows into the pipe (s. arrow).

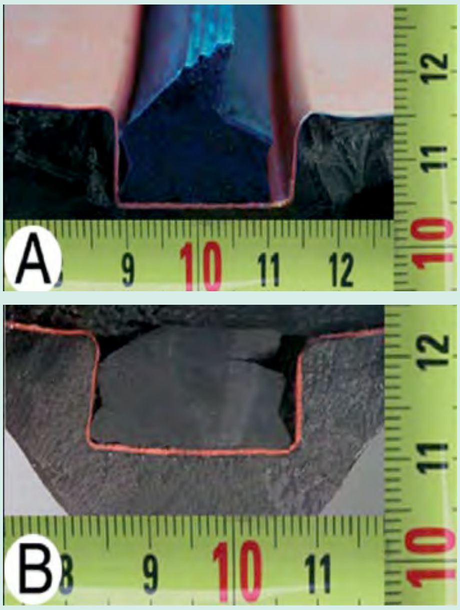


Figure 13: Example for a sliced joint. Socket and seal of a pipe (A). Compressed seal between socket and spigot (B).

for our wood compared to Mangrove plants. The root penetration of the substrate ends, where the oxygen supply falls below a critical limit.

We examined, whether roots perhaps also find pipe connections exclusively along oxygen gradients, since it is known from other investigations, that seals - even if no liquid leaks are present – become permeable for gases over time. The oxygen supply could play a important role by means of pipe systems, particularly in cities, where the gas exchange through the soil surface is strongly reduced by sealing (e.g. road surfaces). We have however so far found no appropriate clues during the excavations.

„Oxygen hypothesis" investigated

This hypothesis could also not be experimentally confirmed yet: We allowed cuttings rooted in clean water, to carry on growing in different waste water concentrations and provided them with oxygen over dialysis tubes. The damaging effect of the waste water could not be compensated and we also did not observe any root growth towards the oxygen source. The experiments do not allow to exclude the „oxygen hypothesis" fully, in case the gas supply of the root should play a role in further experiments, it is a minor one in comparison to the „Density trap model". The „Leak hypothesis" favoured so far could however not be confirmed in our investigations. Not only does the rooting process into the pipes oppose this, the quantities of leaking water also probably do not stimulate the roots sufficiently. Apart from that waste water pipe leaks usually close quickly again. The necessary pressures for noteworthy seeping losses are not achieved at water levels of usually less than 20 cm in the pipe. Penetrating ground water is more of a problem, because the groundwater pressure can considerably exceed the waste water pressure of deeply buried pipes. We are now looking for experimental alternatives to the natural processes, because the growth of roots into conduits takes ten and more years and our results - as in all research projects - have to be presented within approximately two years. We want to shorten the investigation period, using suitable model organisms plentifully available in the RUB Botanical Garden, and by model tests. This is absolutely necessary, because mistakes made in pipe construction during the next ten years will cause immense costs in the coming 50 years.

Consequences for laying pipes

A whole set of consequences for pipe laying can already be deduced from the present results. The rooting problem is not only a question of the seal contact pressure. Geometry and size of the cavity prior to the pipe connection seal play a crucial role, if the „Density trap model" can be further confirmed. The bedding and filling material for pipe trenches are however also of great importance according to this model. The whole pipe trench represents a „Density trap", if the grain size of the filling material offers sufficient pore channels, which roots can easily penetrate: The roots can then more or less grow parallel to the pipe and reach as a consequence nearly all pipe connections. Seal design, bedding and backfilling are therefore under the criterion of the independent variables in pipe laying, but closely inter-dependent factors. It seems justified to hope, that the results of the study will show us, how this pipe damages can be avoided in the future [2].

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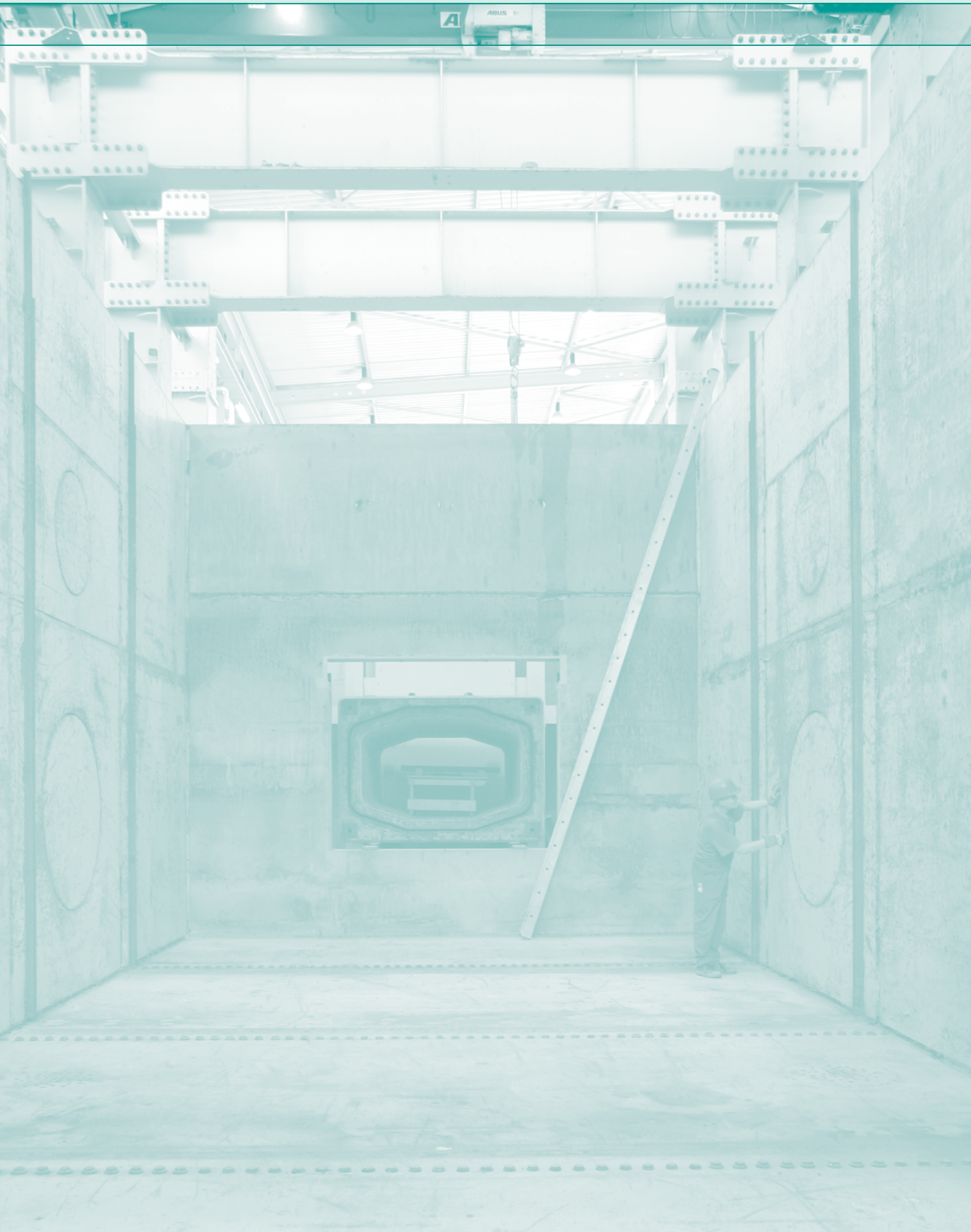
ABUS

Pipe tests under near-realistic stresses

Testing
a pipe until failure

For more than 100 years, concrete and steel reinforced concrete sewer pipes have been tested using the crown pressure test, which is designed to examine to the load bearing behaviour of concrete pipes. However, the crack behaviour of steel-reinforced concrete pipes which is recorded using this so-called ‚classical' method of investigation does not relate to practical conditions; the bonding effect between the concrete and the steel reinforcement is not taken into account and the crack widths are either under- or overestimated. With this in mind, a new testing method has been developed where the actual stresses on earth-covered reinforced concrete pipe can be simulated under near-realistic conditions.

For the first time ever, it is now possible to evaluate the crack formation of a reinforced concrete pipe under design-load conditions as part of a quality assurance system.

A prerequisite for the development and survival of a modern industrial company is a functional infrastructure with reliable supply and disposal networks. The condition of sewers is vitally important for the protection of soil and water. However, in the past, when laying large pipes made from steel-reinforced concrete, so-called 'initial damage' appeared in the form of surprisingly large cracks, in some cases immediately after or a few years after laying.

With this in mind and in view of future investment measures taken by the network operators (cf. [1]) the Department of the Environment in North-Rhine Westphalia, commissioned the IKT Institute for Underground Infrastructure to carry out a research project [2] for investigating the load-bearing and crack behaviour of large steel-reinforced concrete pipes when laid using the open-coverage method. For the first time, in a modified crown pressure test, near-realistic loads are applied which produce the same crack behaviour as that of pipes in the ground. In this case, both the moments and normal forces are measured where previously only the moment stress in the test cross section was taken into account in the 'classical' crown pressure tests. The risks of the design and production of the pipes are also recognized and, where necessary, special quality standards are derived for future construction projects. The important results are presented in the following.

Current technical status

In 2002, 137 manufacturers produced concrete and steel-reinforced concrete pipes which were designed for laying using the open-coverage or closed-coverage method in Germany. The specifications for the steel-reinforced concrete pipe produced include the condition, dimensional accuracy, strength, permeability to water and stability against chemical attacks. Along with the starting materials, the moulding and compaction process are crucial for to pipe quality [11]. The manufacturing process and the degree of mechanisation in the production process may differ from one pipe manufacturer to another. In terms of the production of concrete and steel-reinforced concrete pipes, there is a fundamental difference between methods which involve immediate demoulding and those where the concrete is hardened in the formwork (in-mould hardening).

In regard to the design, it is particularly noticeable that, unlike the normal requirements for reinforced concrete construction, there has so far been no minimum requirement in regard to reinforcement for crack width limitation in steel-reinforced concrete pipes (see German Industrial Standard DIN 4035 [3]). Since April 2003, however, DIN EN 1916 has also applied to the design of steel-reinforced concrete pipes of nominal sizes < 1750 mm [10]. This is destined to replace the German Industrial Standard DIN 4035 [3] from October 2004 at the latest and will also stipulate a minimum reinforcement for steel-reinforced concrete pipes for the nominal size under consideration. This minimum reinforcement is designed so that the permissible stresses which are applied during the crown pressure test can be absorbed. Pipes of nominal sizes > 1750 mm are only stipulated in the national preliminary standard DIN V 1201 [8] which means that there is still no obligatory European regulation for large steel-reinforced concrete pipes available to define a minimum reinforcement.

Steel-reinforced concrete pipes

According to DIN V 1201 [8], steel-reinforced concrete pipes must be made from quality-supervised construction materials. According to DIN EN 1916 [10], the 'classical' crown pressure test can be used as part of the quality assurance of the steel-reinforced concrete pipes produced. This test was derived from a testing method which was developed more than 100 years ago for testing concrete pipes (cf. Figure 1).

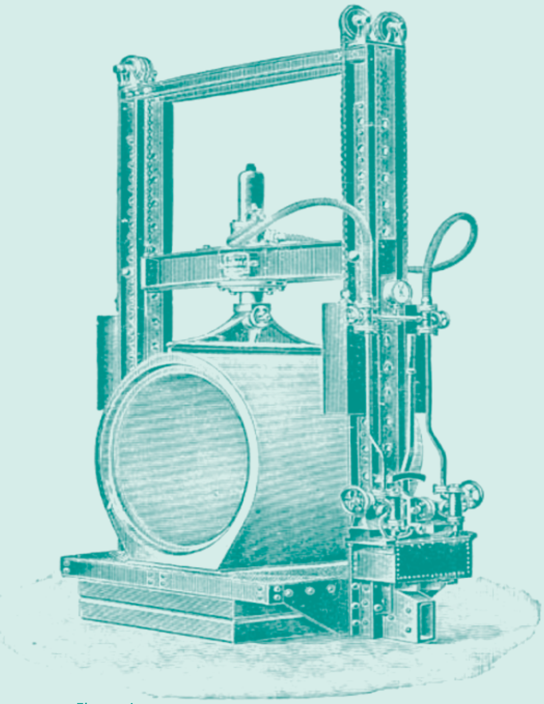

Figure 1:
„Koenen" hydraulic pipe tester from 1909 [6]

The original aim of these tests was to test the annular tensile bending strength of a concrete cross section and, therefore, the load-bearing behaviour of the concrete. The crack-distribution properties of the steel-reinforced concrete are basically not taken into consideration, which means that this method of testing is pushed to its limits for steel-reinforced concrete pipe. So, the standard cross section for the crack formation in the test in particular is 'normal-force free' in the pipe crown, although the pipe in the ground is always subjected to the effect of normal forces. In other areas of underground construction however, such as the testing of steel-fibre reinforced tubbings, tests with simultaneous moment and normal force loading have proved worthwhile (cf [17]).

Development of a modified crown pressure test

As a consequence, the crack behaviour of steel-reinforced concrete pipes should be observed under loads as they actually occur with pipes in the ground. A new testing method has been developed which is based on the experience gained from the 'classical' crown pressure test and simulates the loading to which pipes are subjected in practice as close as possible.

The classical crown pressure test according to DIN 4035 [3] is based on a test which was originally conceived for carrying out load-bearing capacity investigations on concrete pipes. The test is used to discover the edge fibre tensions under which a crack in the concrete structure develops and how the width of this crack develops as the load is increased. The special load-bearing and crack behaviours of steel-reinforced concrete are not taken into consideration during this test. Thus, the interactions between steel and concrete loading (bond) are not taken into account or the effect of the normal force/moment relationship on the crack development.

A preliminary study [3] has already shown that the stress distribution in the pipe wall can be influenced considerably by the choice of a modified experimental arrangement and adapted to the actual load conditions. While pursuing this topic further (cf [7]), the fundamental experimental setup shown in Figure 2 was suggested for the 'modified crown pressure test'. By introducing the horizontal forces in the area of the crossbar, the normal force in the pipe crown in particular increases so that realistic loading can be applied to this crucial test cross section.

It is still open to question, however, how the load conditions made up from vertical and horizontal forces are to be determined in individual cases for a realistic experimental procedure and how the test set-up can be designed and equipped with instruments. Standard crack areas for the evaluation were measured before the test set-up was designed and built on the basis of finite element calculations, so that the entire test arrangement and, in particular, that of the measurement instruments could be aligned to the crack behaviour.

The actual test parameters are specified in principle according to the actual design case to be tested in each case. In the test, the loadings which are actually expected are therefore produced in the measurement cross-section being examined. As one example within the scope of the project, the lateral pressure relationship $b = P_h/P_v$ was selected so that the load condition shown in Figure 3 was simulated in the test.

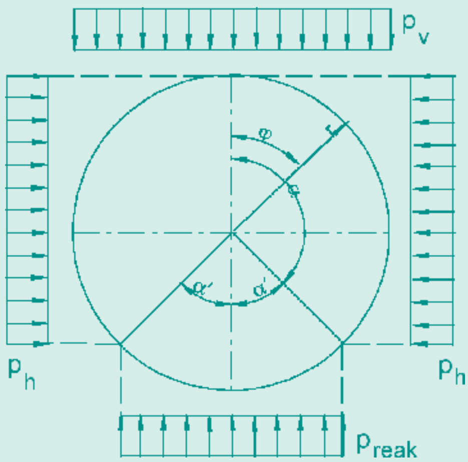

Figure 3: In-situ loading, example [9]

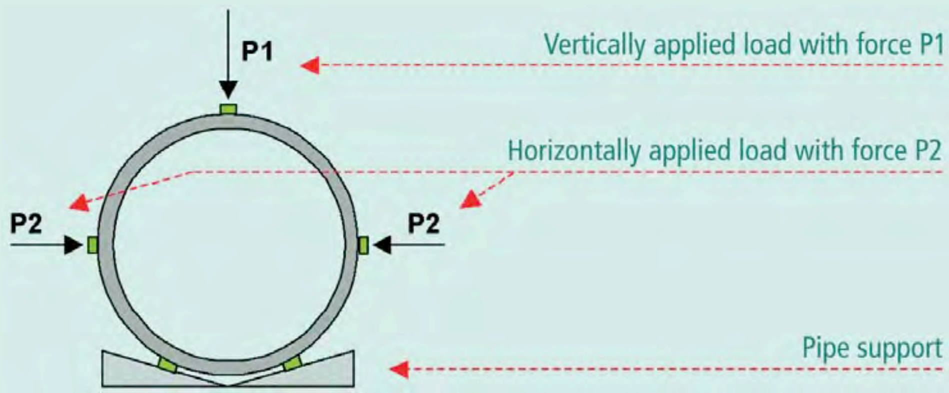

Figure 2: Schematic presentation of the test layout with applied load

In principle, the β ratio which corresponds to the in-situ load case is determined from the vertical force and horizontal supporting force as well as the standard pipe crown force as follows:

1. Determination of the maximum eccentricity for in-situ loading:

The in-situ loading (N/M distribution) is produced by the load conditions present in the installed state, e.g. as determined from permissible stress calculations on the annulus model. The eccentricity for this in-situ loading (e = M/N) is calculated in accordance with the angle at circumference. The maximum amount of eccentricity is a determining factor for the pipe circumference.

2. Determination of the load ratio β

The load ratio β in the crown pressure test gives the relationship between the horizontal supporting force and the vertical crown pressure force. For the 'crown pressure test' load case, the load ratio β is selected so that the maximum eccentricity in the test corresponds to the maximum value under in-situ loading. When considering internal cracking, the relevant cross section area is in the pipe crown but when considering external cracking, it is in the area of the crossbar. Figure 4 shows an example of the eccentricity distribution for any selected in-situ loading and the eccentricity distribution for the selected β-value in the crown pressure test with lateral support for internal crack investigation. The eccentricity at 0° in the crown pressure test in this case corresponds to the 180° value in-situ (standard bottom). Because the normal force within the area of the crossbeam is always large, the eccentricity of the external crack areas is affected less strongly by the choice of the supporting force.

3. Determination of the standard stress magnitude from in-situ loading

The determining factor is the maximum tensile stress on the internal or external surface of the pipe.

4. Determination of the standard crown pressure force

The magnitude of the crown pressure force which can be used to produce the loading which corresponds to the actual loads is determined for the selected β value according to 2 and the tension level according to 3. Figure 5 shows an example of the stress distribution for an in-situ loading and for the crown pressure test with lateral support using the standard crown pressure force. The tensions at 0° (test) and 180° (in -situ) correspond to one other.

In the result, the crack behaviour of the steel-reinforced concrete in the standard test cross section corresponds to the behaviour under design load. For practical application, this means that a direct comparison can be made between the supplied pipe quality and the specifications required under operating conditions for the first time.
A semi-non-destructive test is also possible, if the crack width is only to be examined at crack initiation. Thus, pipes which have already been tested could be approved for further in-situ use, if 'hairline cracks' only appear in the concrete after exceeding the initial crack load and no further load increase is applied during the test.

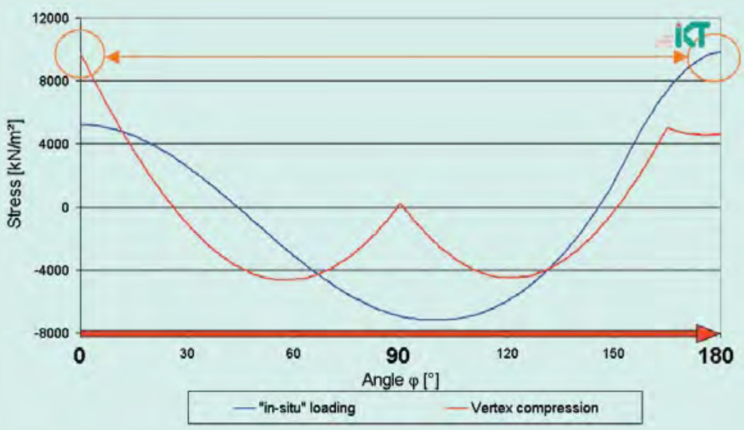

Figure 5: Coordination of the stresses in the standard cross section

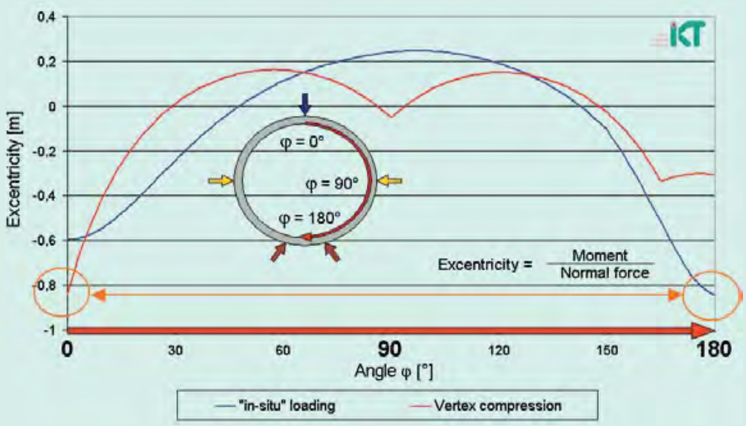

Figure 4: Determination of the load ratio β

Test results

The research project involved carrying out a total of 30 tests on pipes with different reinforcements produced via different manufacturing processes in order to optimise the test sequence and align the measuring program with the quality assurance requirements used in practice. Essentially, pipes were tested which had been

- immediately demoulded,
- hardened in the mould (in-mould hardening) or
- hardened in the mould (in-mould hardening) with concrete post treatment during the production process.

For pipes with nominal sizes > 2000 mm, the production method involved in-mould hardening which is the usual manufacturing variant for the range of observation adopted by the Emscher cooperative (see [15]). All pipe manufacturers which have production capacities for this nominal size range carry out hardening in the formwork (in-mould hardening). According to [15], all manufacturers questioned, which have a significant large-pipe production capacity (> 33 %), had set up their production facility expressly for in-mould hardening.

It should be possible to acquire initial information on qualitative crack behaviour, i.e. regarding the crack processes or crack development under load, by testing pipes which have been produced by different manufacturing methods. No information which could be evaluated statistically was expected on the relationship of the absolute crack widths on pipes produced by different manufacturing methods because of the usually large scatter (cf [14]) for the selected sample size. Steel-reinforced concrete pipes from only one manufacturer were used, so it is not possible to apply the quantitative information to other manufacturers or even other production processes.

Consequently, the investigation centred on the load-dependent recording of the crack development and the comparative interpretation of the characteristic cracking processes. However, this demanded a special outlay in regard to

- the design of the test set-up for the load-dependent lateral support for the pipe,
- the recognition of crack initiation in the standard crack by the application of numerous strain gauges, for example,
- the recording of crack width development in the standard crack by means of a video extensometer, for example.

In all cases, the position of the internal reinforcement corresponded to the specifications in the German Industrial Standard DIN 4035 [5], i.e. the permissible stresses under load were recorded and minimum reinforcement was not used (cf DIN 1045 [13]). The reinforcement on the pipe exterior involved three types of reinforcement with increasing degrees of reinforcement: I, design according to DIN 4035 [5]; II, degree of reinforcement according to interior reinforcement; III, minimum reinforcement according to DIN 1045 [4] for limiting the crack width w ≤ 0.2 mm. All the pipes were tested in a modified test setup with horizontal support based on the crown pressure test according to DIN EN 1916 [9] or DIN V 1201 [8]. After this test and quarter-rotation, some pipes were submitted to a classical crown pressure test without lateral support.

The following significant observations can be made from the tests:

- As expected, during a test with lateral support i.e. with moment and normal forces, the cracks opened more slowly as the load increased than during a test carried out in accordance with DIN EN 1916 [10] or DIN V 1201 [8] without lateral support. Figure 6 shows an example where the measured development of crack widths from tests with lateral support are compared with those without lateral support for crack widths up to 0.3 mm.
- In the pipe crown, cracks develop on the inside of the pipe which open continuously as the load increases. Individual cracks were restricted during all tests without lateral support, as they were in most cases for pipes which had been subjected to concrete post treatment with lateral support.
- Pipes without concrete post treatment with lateral support showed two to three parallel cracks one after the other. This load and crack behaviour dominated by bending moments and normal forces is oriented to the actual loads during installation on site and significantly improves the quality of the crack-width evaluation in comparison to bending moment loading alone in the crown pressure test according to DIN EN 1916 [10] or DIN V 1201 [8].

The pipes which were subjected to concrete post treatment during manufacture showed smaller crack widths than the pipes which were not subjected to concrete post treatment during manufacture for the same loading phases. By using small degrees of reinforcement, small crack widths initially developed and resulted in comparatively brittle failure under increasing load in some cases (see Figure 7). This type of behaviour brings the previous philosophy in regard to damage evaluation according to ATV M 149 [12] into question. Therefore, the relevant damage class is determined by the crack width on a steel-reinforced concrete pipe alone, i.e. independently of the method of manufacture and degree of reinforcement.

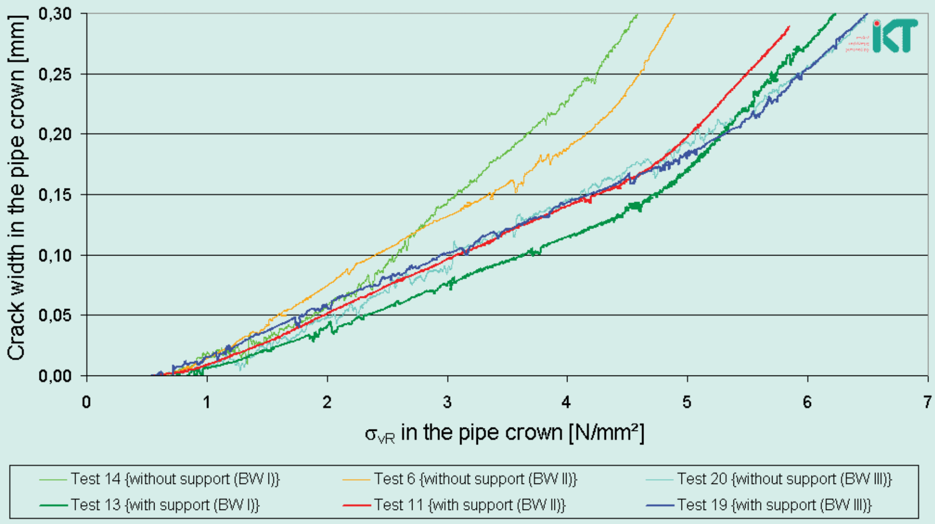

Figure 6: Crack development during tests on pipes cured in the mould
(BW I) Type I reinforcement, (BW II) Type II reinforcement, (BW III) Type III reinforcement

Figure 7: Testing a pipe to failure

- The crack width development can be reduced by both specifying a minimum reinforcement and improving the bond behaviour through concrete post treatment. However, a small degree of reinforcement cannot be compensated for by improved post treatment since this also reduces the load-bearing capacity; the post treatment merely affects the bond behaviour and therefore the crack width development.

Apart from the most important information gained about the test procedure, cracking and crack development described above, it was possible to draw other conclusions from further test observations.

- Depending on the manufacturing method, differences were found in the dimensional accuracy and the surface texture of the pipes. The pipes which were hardened in the formwork had significantly better properties than those which were immediately demoulded.
- In some cases, one possible weak point was found in the design of the lifting anchor system. If necessary, the extent to which the corrosion protection of the reinforcement or the water tightness of the pipes is impaired by this must be questioned.
- As well as the video measurement technique for crack recognition and pursuit, an ultrasonic measuring procedure was also used to discover whether it was possible to determine the depth of the crack. Meaningful results can only be obtained, however, by using very high resolution scanning at correspondingly high measurement cost. External cracks could neither be recognized nor measured from inside the pipe under the given boundary conditions.

Summary

For practical application, the following conclusions can be drawn from the results of the research project.

- In the 'classical' crown pressure test, the crack development in the pipe crown is overestimated because the effects of the normal force are missing. As a consequence, perfectly produced pipes are suspected of excessive cracking. On the other hand, pipes with bad bond properties may be unjustifiably promoted by reference to test conditions which are not in line with standard usage, based on the assumption that outside, such loads and the corresponding crack developments do not occur.
- The new modified crown pressure test allows the crack behaviour of steel-reinforced concrete pipes to be examined under near-realistic load conditions, i.e. moment and normal force loading, so that a pipe can be tested under actual design conditions. As well as concrete strength, crack development and bond behaviour between the steel and concrete can also be evaluated in line with standard usage.
- If the selected design conditions, such as the concrete covering and spacing of reinforcement layers, deviate substantially from the usual formulations for steel- reinforced concrete so that the applicability of the calculation is in doubt, supplementary investigations using the modified crown pressure test could provide additional security.
- If boundary conditions exist on the construction site other than those used in the structural analysis, such as the width, shape and depth of the excavation and the placement and pouring conditions, then a new structural analysis must be provided. If pipes are to be used which have already been manufactured and were originally intended for another load case, static load tests carried out on random samples using the modified crown pressure test could provide further security, since the actual crack behaviour of the pipes could be checked under the new design conditions.
- Cracks cannot be detected on the pipe exterior using justifiable means within the scope of the inspection so, for this layer of reinforcement with aggressive groundwater influence in particular, a minimum degree of reinforcement is advisable in each case.
- In-mould hardened pipes with concrete post treatment also developed only very small crack widths under large loads.
- An application of the damage classification system according to ATV - M 149 [12] hardly seems to be meaningful, particularly for in-mould hardened pipes with concrete post treatment since these pipes can develop small crack widths even under large loads.

In view of the results obtained from the research project, numerous questions which are still unanswered can also be identified. The following points can therefore be raised in regard to future research and test activities.

- In the investigation described here, the loads which were used in the modified crown pressure test were essentially designed for the standard internal pipe crown or bottom area for the initial crack. The supporting force also needs to be selected in relation to the cracking trend which arises in the in-situ state when examining the external cracks.
- In principle, the development of a comprehensive test program to simulate the entire static load history of a pipe (transport, structural condition and operation) for the modified crown pressure test would be advisable.
- Supplementary tests on pipes which have been removed from the ground, such as those recovered during the course of renovation, could provide information on the load-bearing behaviour of previously damaged or corroded pipes.
- The loading of steel-reinforced concrete pipes is possibly subject to numerous interactions and, therefore, complex damage mechanisms. Thus, dynamic loads, biochemical processes and the resulting changes in the load-bearing structure can affect or even accelerate each other. In particular, with difficult construction conditions, the effects of groundwater and various wastewater constituents, further investigations could be of interest in some cases here. As in the procedure described in [16], excavations of steel-reinforced concrete pipes with internal cracks after many years of use would be useful to better understand the crack behaviour on the pipe exterior under operating conditions and evaluate the risk of external cracking on the basis of internal cracks which have already been detected.

Steel-reinforced concrete pipes

- In order to utilize the material properties of the steel-reinforced concrete better in sewer construction, new design rules, which are oriented to experience gained from handling water-impermeable concrete etc. could be worked out for the service load analysis.
- The updating of the test documentation as part of a random-sample-based quality assurance system for future construction projects could provide further knowledge on quality effects determined by production. The maximum delivery quality of a certain pipe manufacturer could also be determined by testing product samples (sample tubes).

Future IKT investigations are beginning – in close collaboration with interested network carriers.

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Source: Bosseler, Redmann
CPI 5/2004 Congress

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.

Current IKT-Product-Tests:

- IKT-Product-Test "Repairing methods for main pipes"
  At the moment IKT is testing about 14 different repairing methods (Partliner, Injection methods, Steel gaskets) together with 25 network operators.
- 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)

Completed IKT-Product-Tests:

- IKT-Product-Test "Tube liners for lateral pipes" (November 2005)
  See page 75
- IKT-Product-Test "Inspection systems for domestic sewer networks" (September 2005)
  See page 81
- IKT-Product-Test "Repair methods for lateral connections" (June 2004) Download: www.ikt.de/down/english/Testing_Liners_2005.pdf (250 KB)
- 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 September 2006)

contact IKT
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Lateral liner wanted: fitted, no crease and tight

Installation of the laterals
at the IKT large-scale test facility

Fitting accuracy, flat surface and leaktightness: the latest IKT-Product-Test „Liners for Laterals“ shows which liners fulfil the requirements of the network operators. The marks range from „VERY GOOD“ to „POOR“. Even the best liner, however, is not always free of malfunction.

Rehabilitation of public and private sewers

The rehabilitation of laterals is becoming increasingly important. With high proportions of extraneous water the cost-intensive rehabilitation only really makes sense if the private sewers are rehabilitated, too. However, laws as well as standards require tight laterals such as §61a NRW-Wassergesetz (water regulations North Rhine Westphalia) and DIN 1986.

The technical demands on the rehabilitation of laterals with cured-in-place pipes (CIPP) are tremendous. They have far smaller diameters (e. g. DN 150 and smaller) than public collector lines. They are often marked by tight bends up to 90 degrees. Furthermore, in many cases the accessibility is far more limited than in public space. In addition, numerous practical investigations by IKT show that their damage rate is clearly higher than the one of „large“ sewers, namely more than 70%.

For this reason the NRW Ministry of Environment and 14 sewer network operators wanted to learn more about the suitability of cured-in-place pipes for rehabilitating laterals. They all put the IKT – Institute for Underground Infrastructure in charge of the product test „Liners for laterals“. The following network operators participated in the product test:

- Eigenbetrieb Abwasser Stadt Alsdorf
- Abwasserwerk Stadt Bergisch Gladbach
- Stadt Dinslaken
- Stadtentwässerungsbetrieb Düsseldorf
- Stadt Gladbeck
- Stadtentwässerung Göttingen
- Stadt Hilden
- Stadtentwässerungsbetriebe Köln AöR
- Stadt Neuss
- Niederrheinische Versorgung und Verkehr AG (NVV)
- Stadtwerke Quickborn
- Stadt Recklinghausen
- Entsorgungsbetriebe Warendorf
- Staatliches Hochbauamt Würzburg

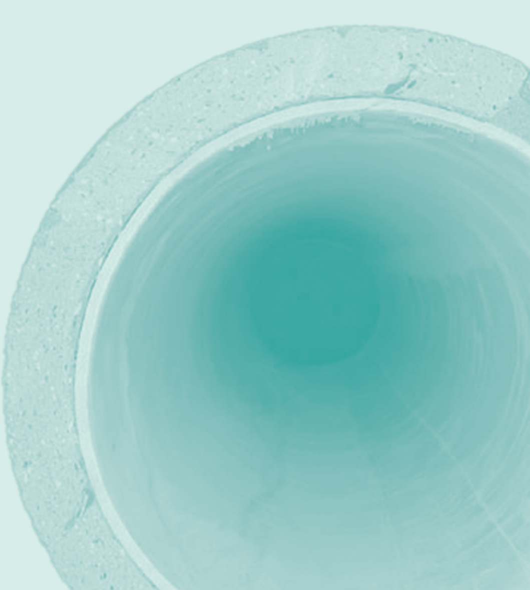
Meeting of the steering committee: network operators examine liner samples

Together with IKT, in the meetings of the steering committee the 14 network operators developed the test programme, selected the test candidates and assessed the test results afterwards.

Liner in the test

The IKT-testers assessed the following eight liners:

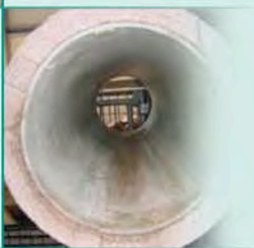
- BendiLiner, EasyLiner GmbH
- Brawoliner-Fix, KOB KG
- DrainLiner, epros GmbH
- DrainPlusliner, epros GmbH
- Flex-Liner, ALOCIT Chemie GmbH
- Konudur Homeliner, MC Bauchemie Müller GmbH & Co. KG
- ProFlex Liner (prototype), VFG AG
- SoftLiner, EasyLiner GmbH



BendiLiner,
EasyLiner GmbH

Brawoliner-Fix,
KOB KG

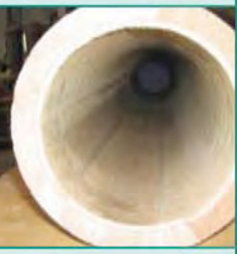
DrainLiner,
epros GmbH



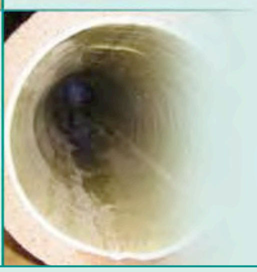
DrainPlusliner,
epros GmbH

Flex-Liner,
ALOCIT Chemie GmbH

Konudur Homeliner,
MC Bauchemie Müller
GmbH & Co. KG



ProFlex Liner (Prototype),
VFG AG



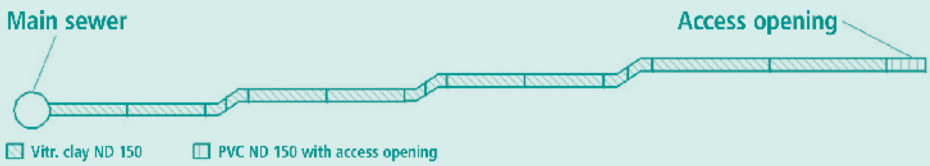
Soft-Liner,
EasyLiner GmbH

Two other liner manufacturers declined to take part in the product test. For details see result tables.

Test set-up

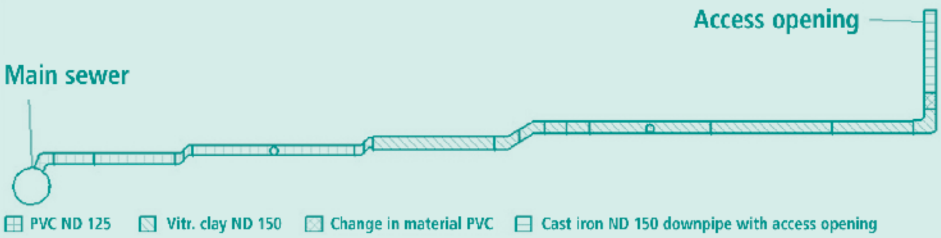
For the product test the IKT-testers installed laterals with defined damages in the IKT large-scale test facility. Here, they differentiated between two applications:

„Standard situation": vitrified clay sewer DN 150 with several bends and damages, rehabilitation via an inspection opening at the ground surface.



Standard situation

„Extreme situation": vitrified clay sewer DN 150 with change of dimension and material transition to PVC sewer DN 125 as well as several bends and damages, rehabilitation via an inspection opening at a downpipe.



Extreme situation

Test results

Overall result

The winner of the test is the „Brawoliner-Fix" by KOB with an overall score of „GOOD" in the standard situation and „VERY GOOD" in the extreme situation.

The „Flex-Liner" by ALOCIT Chemie GmbH and the „ProFlex Liner" by VFG AG, of which only a prototype entered the race, were at the bottom of the list. It could be observed that all test candidates improved the operability of damaged laterals even in extremely bent laterals. Numerous liners, however, presented disappointing results in the very important leaktightness test. Here, only three of the eight tested liners are „GOOD" and better.

Varying quality

All cured-in-place liners showed variations in the liner properties. The IKT-testers noticed these variations in the circumference of the liners, e.g. when measuring the wall thickness, as well as in the length of the liner, e.g. when determining the density. The results of the leaktightness tests according to the APS guideline underline the varying quality of the liners. The dispersion of the results even partially leads to apparent contradictions in the test results. So due to these variations the „Brawoliner-Fix" performs better in the extreme situation („VERY GOOD") than in the standard situation („GOOD").

Testing bodies (30 cm) with tight (2) and leaking (4 und 5) spots

Operation strains with minor influence

The strains introduced during HP cleaning and mechanical cleaning (spiral machine with various fittings) do not noticeably affect the liner quality. The dispersion of the material properties obviously dominates the result of the leaktightness tests. As a consequence of the strains usually only the inner foil is roughened or damaged in some parts. The IKT-testers did not notice changes in the carrier material.

Light damages in the inner foil after mechanical strains

Conflict of aims between operability and tightness

Nearly all tested liners achieved better results in the recovery of operability than in leaktightness. A rehabilitation can be considered successful if the liner does not show any or only few creases and edges. To achieve this the liner material needs to have adequate flexibility especially in bends. This flexibility, however, can oppose the leaktightness of the material.

In the test this became particularly clear when several liner suppliers used different liners for rehabilitating the standard and the extreme situation. So „DrainPlusliner“ and „BendiLiner“, which were exclusively used in the extreme situation, showed far less creases in bends than the ones used in the standard situation „DrainLiner“ and „SoftLiner“. But, less creases in these cases led to clear loss in the sealing effect and thus to a worse overall result.

Quality assurance in preparation

Merely the test winner is able to convince in quality assurance with the score „VERY GOOD“. Most suppliers provided incomplete or even no documents at all. Partially the documents refer to other materials than used in the test. However, many providers stated that they were currently improving the quality assurance of their products. According to this, three providers applied for a license by the Deutsches Institut für Bautechnik (DIBt) for their liners.

Additional investigations of practice

In addition to their laboratory experiments, the IKT-Product-Testers visited selected construction sites where they inspected the procedures of the rehabilitating personnel and assessed the rehabilitation results. The gained impressions confirm the results gathered at IKT. It was found out that with the procedures liners can be installed under practical conditions (little working space, time pressure). Still the IKT testers found variations in quality, in the length of the liner and its circumference by carrying out random leaktightness tests.

Liner inversion under difficult basic conditions

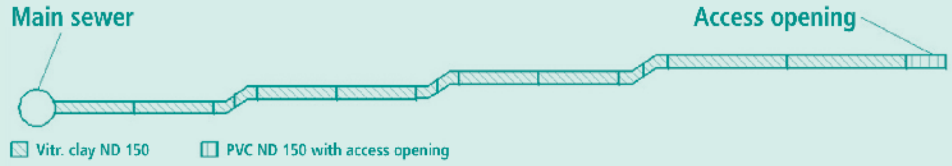
Conclusions

Liners are not only suitable for rehabilitating public sewers, but just as well for rehabilitating smaller laterals. Here, there are numerous constructional challenges, however, under equally high demands on fitting accuracy, flat surfaces and leaktightness. The test shows that there are indeed liners that meet these requirements – but until today still too less. This is why property owners should take a closer look by means of which liner they have their laterals rehabilitated. For liner suppliers with less good results shows the test primarily the potential for improvements. The results clarify which product characteristics still need improvement. Hopefully, the suppliers regard the results as helpful criticism and act in a corresponding way. After all the aim of the independent and neutral IKT-Product-Tests is to build up pressure on the market quickening technical innovations and thus contributing to better products and methods.

Source: IKT-eNewsletter November 2005

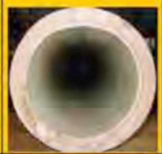
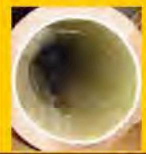
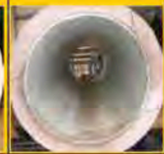
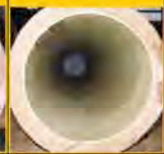
Tables with the results see following pages...

IKT - Product test „Lateral Liner"



Standard situation[1]

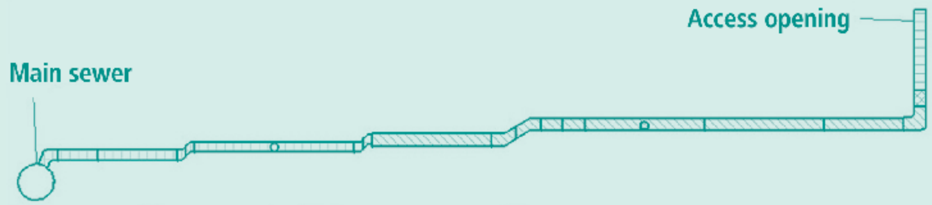
Refurbishment of three vitrified clay lateral pipes 150mm diameter; correct connection with a connection fitting in the springer of the main pipe; inversion through access openings at the start of the vitrified clay sewer; vertical bends: 45° and 30°; applied damage: longitudinal cracks, transverse cracks, fragmenting, missing pipe pieces.

Liner supplier	KOB KG	epros GmbH	MC Bauchemie Müller GmbH & Co. KG	EasyLiner GmbH	ALOCIT Chemie GmbH	VFG AG	epros GmbH	EasyLiner GmbH	Mr. PIPE GmbH	Insituform Rohrsanierungs-techniken GmbH
Tube liner	BRAWOLINER - FIX 	DrainLiner 	Konudur Homeliner 	SoftLiner 	Flex-Liner 	ProFlex Liner (Prototyp) 	DrainPlusliner 	BendiLiner 	Mr. PIPE-Liner -	Insituform-Liner -
Basic material	Polyester high-strength fabric with PU foil	Polyester needle felt with PVC foil	Polyester needle felt with PU foil	Polyester needle felt with PU foil	Knitted polyester fabric with PVC foil	Meshed felt with PU foil	-	-	-	-
Resin system	Brawo I	EPROPOX VIS A4/B4	Konudur 160 PL-XL	EasyPox 3008	ALOCIT A 480, B 48.48 resp. 48.94[8]	Biresin LS	-	-	-	-
IKT test mark: standard situation	**GOOD (1.6)**	**SATISFACTORY (2.6)**	**SATISFACTORY (2.8)**	**SATISFACTORY (3.3)**	**ADEQUATE (4.2)**	**ADEQUATE (4.4)**	**NOT ASSESSED**	**NOT ASSESSED**	**NOT ASSESSED**	**NOT ASSESSED**
System test (weighting 80%)	**good (1.6)**	**good (2.3)**	**good (2.1)**	**satisfactory (3.0)**	**adequate (3.7)**	**adequate (4.0)**	• Tube liner was not used • Reason: supplier decided to use the DrainLiner for refurbishment of the standard situation	• Tube liner was not used • Reason: supplier decided to use the SoftLiner for refurbishment of the standard situation	• Participation declined • Supplier's reason: quality already verified to an adequate extent by other documents (including DIBt certification) • Complete letter declining participation dated 27.01.2005 included in Annex I of the final report	• Participation declined • Supplier's reason: test conditions outside the specifications of the Insituform-Liner • Complete letter declining participation dated 14.02.2005 in Annex II of the final report
Refurbishment result (60%) – Operability[2] (40%)	1.7	2.4	2.2	2.9	2.6	2.1				
Refurbishment result (60%) – Tightness[3] (60%)	1.8	2.7	1.8	3.5	3.5	4.3				
Tightness after HP cleaning[3] (20%)	1.0	1.0	2.7	1.0	4.3	4.3				
Tightness after mechanical cleaning[3] (20%)	1.6	2.7	2.1	4.3	4.9	5.4				
Quality assurance (weighting 20%)	**very good (1.5)**	**adequate (4.0)**	**poor (5.5)**	**adequate (4.5)**	**inadequate (6.0)**	**inadequate (6.0)**				
DIBt certification[4] (50%)	yes	no	no	no	no	no				
Environment compatibility test certificate submitted for the resin[4] (20%)	yes[5]	yes	no	yes[7]	no	no				
Procedure manual and training courses[4] (10%)	yes	yes	no	no	no	no				
External monitoring[4] (10%)	yes	yes	yes	yes	no	no				
Evidence of disposability[4] (10%)	no	no	no	no	no	no				
Construction site investigation	practice-orientated installation	not carried out	practice-orientated installation	practice-orientated installation	practice-orientated installation	practice-orientated installation				
Additional information: available for	70mm to 200mm	100mm to 300mm	100mm to 300mm	70mm to 1200mm	50mm to 300mm	70mm to 200mm				
Recommended improvements	Reduce fluctuations in the liner properties	Reduce fluctuations in the liner properties; extend DIBt certification to include the used resin system	Reduce fluctuations in the liner properties; improve quality assurance	Reduce fluctuations in the liner properties; improve tightness and quality assurance	Reduce fluctuations in the liner properties; improve tightness and quality assurance	Reduce fluctuations in the liner properties; improve tightness and quality assurance				

1 "Standard situation" refers to the geometry of the lateral pipe.
2 Assessment of the operability through visual inspection of the refurbished standard situation by the sewage network operators: 100 points = 1.0 to 0 points = 6.0; marks depicted by a linear function.
3 Assessment: 100% tightness tests passed according to APS guideline = 1.0 to 0% tightness tests passed according to APS guideline = 6.0; marks depicted by a linear function.
4 Assessment: present = yes, not present = no; certifications/certificates/verfications must be valid for the materials used in the test.
5 According to the DIBt certification, a PE protective tube is to be used between the liner impregnated with resin and the pipe being refurbished when using the refurbishment method in areas saturated with ground water.
6 The liner was not used by the participating sewage network operators at the point in time of the site tests; the liner supplier could not name a site either. The installation procedure corresponds basically to that used for the DrainPlusliner.
7 Test certificate of the Hygiene Institute of the Ruhr area dated 1 August 2002: "Given the clear smell and taste contamination of the test water, it is advisable as a precaution to refrain from using in direct drinking water catchment areas (protection zone I) and in protection zone II"..." In our opinion [there] are no objections to using the material "EasyPox" in areas with groundwater contact, as long as these are above the saturated zone and outside drinking water protection zone II".
8 Both B-components (hardeners) 48.48 resp. 48.94 were available and were used.

Assessment key for the test results: very good = 1.0 – 1.5, good = 1.6 – 2.5, satisfactory = 2.6 – 3.5, adequate = 3.6 – 4.5, poor = 4.6 – 5.5, inadequate = 5.6 – 6.0

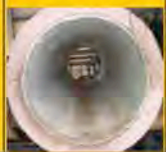
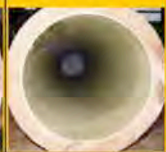
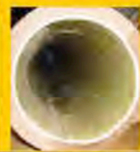
IKT - Product test „Lateral Liner“



PVC ND 125 | Vitr. clay ND 150 | Change in material PVC | Cast iron ND 150 downpipe with access opening

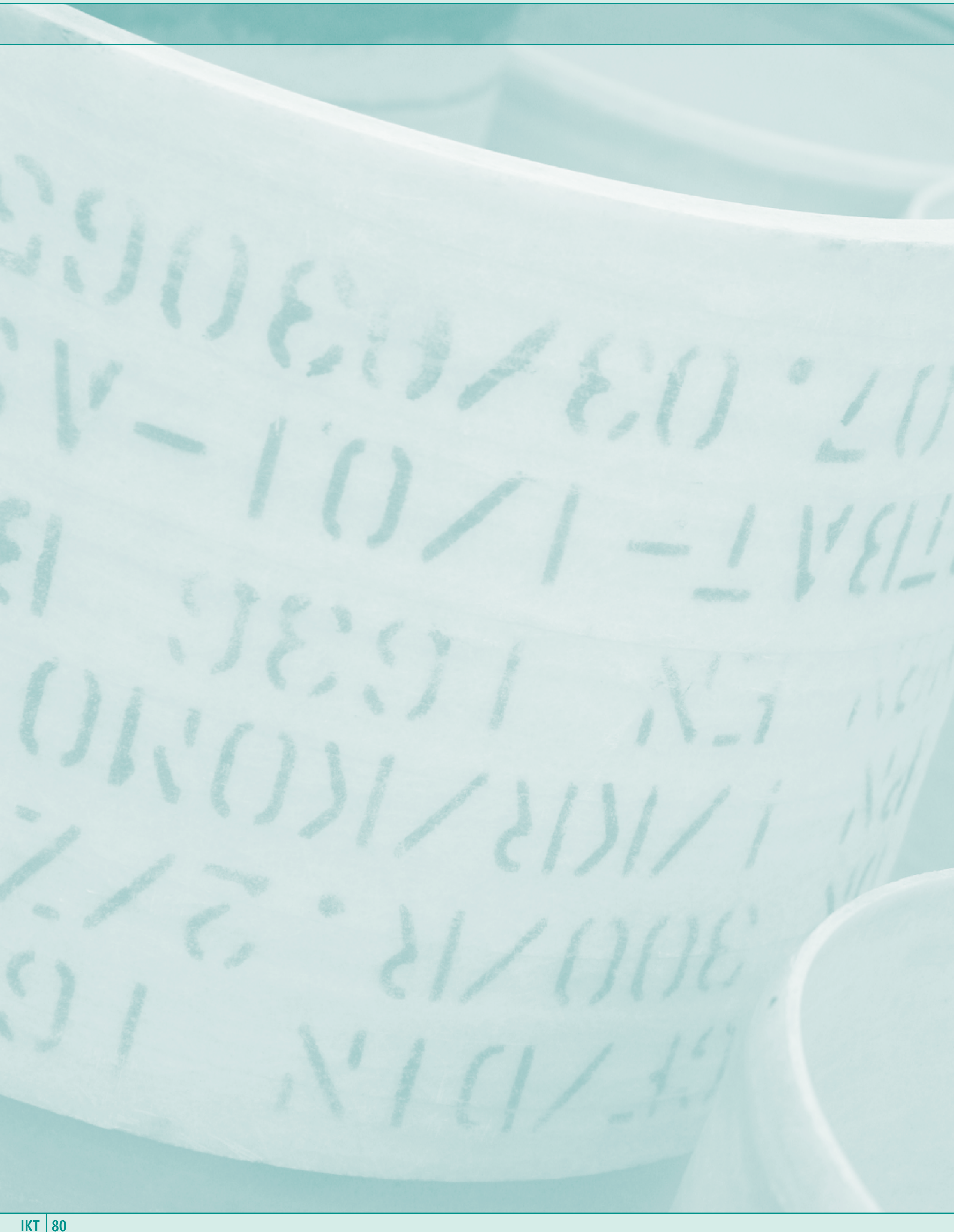
Extreme situation[1]

Refurbishment of three lateral pipes of vitrified clay 150mm diameter with change in dimension and material to PVC 125mm diameter; connection between crown and springer of the main sewer not correctly executed with mortar coated 67° bend; inversion through access openings in the downpipes made of cast iron 150mm diameter; vertical bends: 90°, 45° and 30°; horizontal bends: 15°; applied damage: longitudinal cracks, transverse cracks, fragmenting, lacking pipe pieces, indicated side inlets, lacking gaskets.

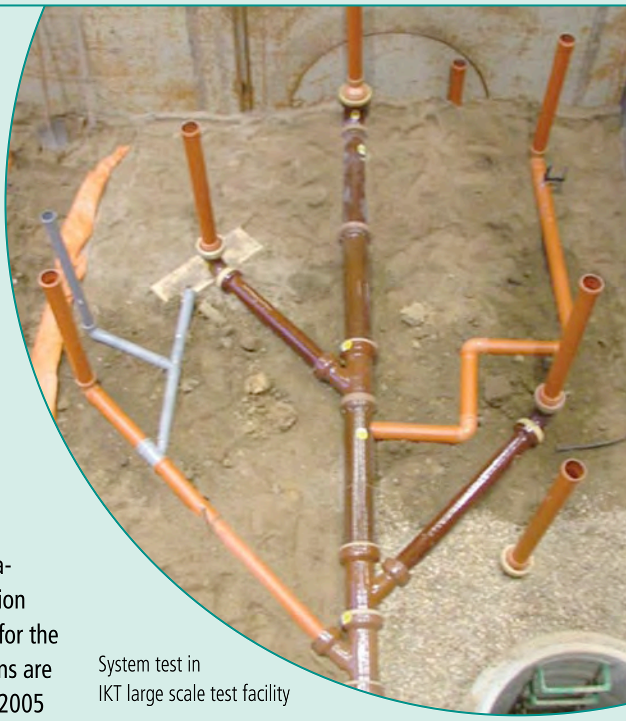
Liner supplier	KOB KG	MC Bauchemie Müller GmbH & Co. KG	epros GmbH	EasyLiner GmbH	VFG AG	ALOCIT Chemie GmbH	epros GmbH	EasyLiner GmbH	Mr. PIPE GmbH	Insituform Rohrsanierungs-techniken GmbH
Tube liner	BRAWOLINER - FIX 	Konudur Homeliner 	DrainPlusliner 	BendiLiner 	ProFlex Liner (Prototyp) 	Flex-Liner 	DrainLiner 	SoftLiner 	Mr. PIPE-Liner -	Insituform-Liner -
Basic material	Polyester high-strength fabric with PU foil	Polyester needle felt with PU foil	Polyester needle felt with PU foil	Polyester needle felt with PU foil	Meshed felt with PU foil	Knitted polyester fabric with PVC foil	-	-	-	-
Resin system	Brawo I	Konudur 160 PL-XL	EPROPOX VIS A4/B4	EasyPox 3008	Biresin LS	ALOCIT A 480, B 48.48 resp. 48.94[5]	-	-	-	-
IKT test mark: extreme situation	**VERY GOOD (1.3)**	**SATISFACTORY (3.2)**	**ADEQUATE (3.9)**	**ADEQUATE (4.1)**	**POOR (4.6)**	**POOR (5.1)**	**NOT ASSESSED**	**NOT ASSESSED**	**NOT ASSESSED**	**NOT ASSESSED**
System test (weighting 80%)	very good (1.2)	satisfactory (2.6)	adequate (3.9)	adequate (4.0)	adequate (4.3)	poor (4.9)	• Tube liner was not used • Reason: supplier decided to use the DrainPlusliner for refurbishment of the extreme situation	• Tube liner was not used • Reason: supplier decided to use the BendiLiner for refurbishment of the extreme situation	• Participation declined • Supplier's reason: quality already verified to an adequate extent by other documents (including DIBt certification • Complete letter declining participation dated 27.01.2005 included in Annex I of the final report	• Participation declined • Supplier's reason: test conditions outside the specifications of the Insituform-Liner • Complete letter declining participation dated 14.02.2005 in Annex II of the final report
Refurbishment result (60%) – Operability[2] (40%)	1.9	2.6	1.7	2.4	2.9	3.5				
Refurbishment result (60%) – Tightness[3] (60%)	1.0	4.3	4.3	6.0	6.0	6.0				
Tightness after HP cleaning[3] (20%)	1.0	1.0	4.3	1.0	1.0	4.3				
Tightness after mechanical cleaning[3] (20%)	1.0	1.0	5.2	5.2	6.0	5.2				
Quality assurance (weighting 20%)	very good (1.5)	poor (5.5)	adequate (4.0)	adequate (4.5)	inadequate (6.0)	inadequate (6.0)				
DIBt certification[4] (50%)	yes	no	no	no	no	no				
Environment compatibility test certificate submitted for the resin[4] (20%)	yes[6]	no	yes	yes[7]	no	no				
Procedure manual and training courses[4] (10%)	yes	no	yes	no	no	no				
External monitoring[4] (10%)	yes	yes	yes	yes	no	no				
Evidence of disposability[4] (10%)	no	no	no	no	no	no				
Construction site investigation	practice-orientated installation	practice-orientated installation	practice-orientated installation	practice-orientated installation	practice-orientated installation	practice-orientated installation				
Additional information: available for	70mm to 200mm	100mm to 300mm	100mm to 300mm	100mm to 150mm	70mm to 200mm	50mm to 300mm				
Recommended improvements	Reduce fluctuations in the liner properties	Reduce fluctuations in the liner properties; improve quality assurance	Reduce fluctuations in the liner properties; improve tightness; extend DIBt certification to include the used resin system	Reduce fluctuations in the liner properties; improve tightness and quality assurance	Reduce fluctuations in the liner properties; improve tightness and quality assurance	Reduce fluctuations in the liner properties; improve tightness and quality assurance				

1 "Extreme situation" refers to the geometry of the lateral pipe.
2 Assessment of the operability through visual inspection of the refurbished standard situation by the sewage network operators: 100 points = 1.0 to 0 points = 6.0; marks depicted by a linear function.
3 Assessment: 100% tightness tests passed according to APS guideline = 1.0 to 0% tightness tests passed according to APS guideline = 6.0; marks depicted by a linear function.
4 Assessment: present = yes, not present = no; certifications/certificates/verifications must be valid for the materials used in the test.
5 Both B-components (hardeners) 48.48 resp. 48.94 were available and were used.
6 According to the DIBt certification, a PE protective tube is to be used between the liner impregnated with resin and the pipe being refurbished when using the refurbishment method in areas saturated with ground water.
7 Test certificate of the Hygiene Institute of the Ruhr area dated 1 August 2002: "Given the clear smell and taste contamination of the test water, it is advisable as a precaution to refrain from using in direct drinking water catchment areas (protection zone I) and in protection zone II"..." In our opinion [there] are no objections to using the material "EasyPox" in areas with groundwater contact, as long as these are above the saturated zone and outside drinking water protection zone II".

Assessment key for the test results: very good = 1.0 – 1.5, good = 1.6 – 2.5, satisfactory = 2.6 – 3.5, adequate = 3.6 – 4.5, poor = 4.6 – 5.5, inadequate = 5.6 – 6.0.



Inspection-Systems for Domestic Sewer Networks



System test in
IKT large scale test facility

The objective of IKT-Product-Tests is to provide network operators with reliable and independent information on the properties of products of the pipe technology. Such information has been almost completely missing for the pipeline construction and rehabilitation area until now. The clients attain information on product characteristics almost exclusively from advertisements and the offerers' brochures, who try to convince potential customers of the alleged quality of a product. The aim is, to assess the quality of products available on the market, to indicate potentials for improvement and simultaneously to develop an appropriate market pressure so that product suppliers will indeed exploit these potentials.

A central aspect of the IKT-Product-Test is the practical product quality evaluation, e. g. under 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 the expected conditions and loads, such as e. g. groundwater, earth pressures, volume of traffic or high-pressure cleaning, are 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 main focus during IKT-Product-Tests is on three examinations: Process offerer quality assurance, system tests and building site investigations. At the end of IKT-Product-Tests a score card with a comparative evaluation of the products is developed on the basis of the test results. Test marks are formulated using the quality assurance of the process offerers and system tests as investigation priorities. The building site investigation results were not taken into consideration for the test marks, because building site conditions are not comparable. In this way IKT tested in 2005 special, new-developed devices for the inspection of domestic sewer networks.

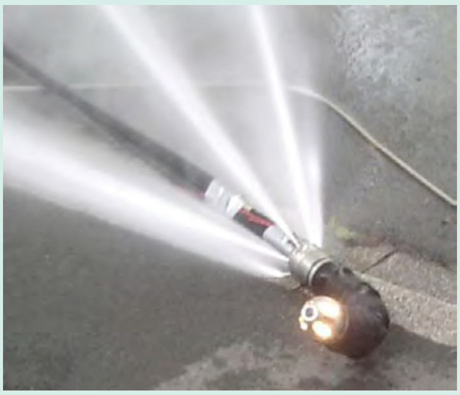
From "Aaligator" to "Worm"

In North-Rhine-Westphalia, Section 45 of the Regional Building Regulations [1] specify that the owner of a piece of land must have older laterals and base lines in water protection areas checked for leaks by 31st December 2005. Newer laterals and base lines, and those outside water protection areas, must be inspected by 31st December 2015. In recent years the industry has reacted and developed special inspection systems for the use in domestic sewer networks. These remarkably small and manoeuvrable cameras are particularly suitable for the inspection of the narrow and highly branched networks out of the main sewer or demarcation chamber/ manhole. But what can these systems do? This question was answered in the IKT-Product-Test. The following inspection systems were closely examined:

The "Aaligator" is a hydraulically driven camera system. The drive unit has a collar of hydraulic nozzles. The optical unit consists of an axial camera and incorporates nozzles aimed laterally, so that the system can move sideways. Manually turning the high-pressure hose at the same time makes it possible to turn to other lateral/base line branches.

The hydraulically driven "Göttinger ZK-Kanalwurm 70/500" (Göttingen ZK Drain Worm) includes a carriage unit with an axial camera mounted in the head of the carriage. The system can be turned up to 90° to the side, and if the "worm" is advanced at the same time, it can be made to turn into lateral/ base line branches. In addition to its function as an inspection unit, the "worm" can be used as a blocking unit for leak tests.

Aaligator, Schwarz Umweltservice GmbH



Göttinger ZK-Kanlawurm 70/500, IMS Robotics GmbH

The successor model of the "Göttinger ZK-Kanalwurm 70/500" with rotary/pivoting head offers the features of the "old" worm model, while the camera's pan/tilt head also makes it possible, for instance, to pivot over a damage. This model is also fitted with a front rinsing unit, with which the camera lens can be cleaned.

Göttinger ZK-Kanalwurm 70/500 with rotary/pivoting head, IMS Robotics GmbH

The "Göttinger ZK-Kanalwurm 50/300" is a smaller version of the "Göttinger ZK-Kanalwurm 70/500". The small worm was specially developed to inspect laterals/ base lines with very narrow nominal widths. The short carriage unit is fitted with an axial camera. The worm can be turned smoothly in four directions by up to 90°. It is not possible to pivot over a damage. The small worm has not been designed as a blocking unit for leak tests.

Göttinger-ZK-Kanalwurm 50/300 (mini), IMS Robotics GmbH

Lindauer Schere, JT elektronik GmbH

The "Lindauer Schere (mini)" (Lindau shear) consists of a camera on a pan/tilt head onto which an extendable mechanical scissors unit has been mounted. When examining a branching lateral/base line, the camera head is turned in the direction of the branch that is to be recorded, and the scissors are extended. The system is therefore turned into the branch when it is further advanced. The scissors are then withdraw again.

ORION L (Kieler Stäbchen), IBAK Helmut Hunger GmbH & Co. KG

The "Orion L (Kieler Stäbchen)" (Kiel bars) consists of camera on a pan/tilt head to which a guide bar has been fastened. This is not telescopic. The Orion L is turned into the branching lateral/base line with the aid of the glass fibre rod and enters as it is advanced further. The guide bar always remains in the camera's view during optical inspection.
To test the inspection-systems IKT built a test bed in its industrial size test rig (18 m x 6 m x 6 m), corresponding to real domestic sewer networks. Six different inspection-systems had been examined during these system tests. The tasks for the companies who submitted their systems for test purposes, were to find out the structure of the networks and to localize damages which had been created in the pipes. For the technicians who carried out the inspections was not visible that the three networks which had been built were identical. This circumstance had consequences with interesting results. Furthermore the quality assurance of the companies for their inspection systems was investigated and the application of the inspection-systems in present domestic sewer networks was accompanied in the cities of Gelsenkirchen, Göttingen and Würzburg.

Because of the test results all the tested inspection systems were evaluated with the test mark "GOOD" in the finally developed score card. Nevertheless they have all there advantages and disadvantages for the use in domestic sewer networks.

Final conclusion

The IKT-Product-Test "Inspection-Systems for Domestic Sewer Networks" is the third IKT-Product-Test (cf. IKT-Product-Tests "Lateral connections" [2] and "Repair methods for lateral connections" [3]). The eager participation of sewer network operators in the IKT-Product-Tests underlines their practical significance. The way the test results are accepted in the trade also shows what a demand there is for comparative product tests in sewer technology. The IKT product tests support the "circle of product improvement" (cf. [4]) and the development of improved or even new products (cf. [5]). The overall aim in future will remain that of improving the quality of the offered products in the interests of the sewer network operators.

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[1] Bauordnung für das Land Nordrhein-Westfalen (BauO NW); in der Fassung und Bekanntmachung vom 07. März 1995, zuletzt geändert am 24. Oktober 1998.

[2] Bosseler, B; Kaltenhäuser, G; Puhl, R: IKT-Warentest "Hausanschluss-Stutzen", IKT - Institut für Unterirdische Infrastruktur; Gelsenkirchen, 06/2002.

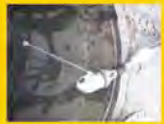
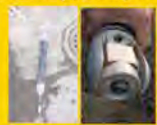
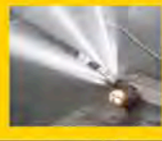
[3] Bosseler, B.; Kaltenhäuser, G.: IKT-Warentest "Reparaturverfahren für Anschlussstutzen", IKT - Institut für Unterirdische Infrastruktur; Gelsenkirchen, 06/2004.

[4] Homann, D.; Kaltenhäuser, G.: IKT-Warentest „Flexoset-Anschlusselement B" – Nachtest zum IKT-Warentest „Hausanschluss-Stutzen"; IKT - Institut für Unterirdische Infrastruktur; Gelsenkirchen, 06/2003.

[5] Kaltenhäuser, G.: IKT-Warentest „Janssen-Verpresssystem mit Mörtel" - Nachtest zum IKT-Warentest „Reparaturverfahren für Anschlussstutzen"; IKT - Institut für Unterirdische Infrastruktur;

Published: March 2006

IKT Product Test „Inspection systems for domestic drainage/sewerage systems“

System supplier	IBAK Helmut Hunger GmbH & Co. KG	JT elektronik GmbH	IMS Robotics GmbH	IMS Robotics GmbH	IMS Robotics GmbH	Schwarz Umweltservice GmbH
Inspection system	**ORION L (Kieler Stäbchen)**	**Lindauer Schere (mini)**	**Göttinger-ZK-Kanalwurm 70/500 with rotary/pivoting head**	**Göttinger-ZK-Kanalwurm 70/500**	**Göttinger Kanalwurm 50/300**	**Aaligator**
 **Inspection of three piping systems with defined artificial damage, consisting of DN 150 connection conduit with branching DN 100 and DN 70 underground lines. Branch angles 45° and 67°, bends 90°. Inspection starting from DN 300 main sewer.**						
Inspection period in the test systems	approx. 7 h	approx. 7.5 h	approx. 4.5 h	approx. 5.5 h	approx. 3 h	approx. 5 h
IKT test mark	**GOOD (2.0)**	**GOOD (2.1)**	**GOOD (2.1)**	**GOOD (2.2)**	**GOOD (2.3)**	**GOOD (2.5)**
System test (weighting 70 %)	**good (2.1)**	**good (2.3)**	**satisfactory (2.6)**	**satisfactory (2.6)**	**good (2.5)**	**satisfactory (2.8)**
Usability*	2.5	2.7	2.8	3.3	2.7	2.3
Degree of registration**	1.6	1.6	1.5	1.4	1.3	2.0
Quality of registration***	2.2	2.7	3.6*****	3.3	3.6*****	4.1
System suppliers' quality assurance (weighting 30 %)	**good (1.7)**	**good (1.7)**	**very good (1.0)**	**very good (1.0)**	**good (1.7)**	**good (1.7)**
Process manual****	yes	no	yes	yes	yes	no
Training available****	yes	yes	yes	yes	yes	yes
Servicing and maintenance available****	yes	yes	yes	yes	yes	yes
Software****	yes	yes	yes	yes	yes	yes
Radio locator****	yes	yes	yes	yes	no	yes
Cleaning from inspection opening****	yes	yes	yes	yes	yes	yes
Cleaning from main sewer****	no	yes	yes	yes	yes	yes
In-situ test						
Basic suitability	+	+	+	+	+	+
Handling	+	+	-	-	-	o
Reach, bend + branch accessing	+	+	+	+	+	+
Damage registration	+	+	No documentation supplied	o	No documentation supplied	-
Additional information						
Costs (smallest deployable unit) [net, in €]	approx. 18.400	approx. 30.000	approx. 50.000	approx. 50.000	22.870	29.800
Delivery time	from stock	approx. 3 - 4 weeks	approx. 8 - 10 weeks	approx. 8 - 10 weeks	approx. 8 - 10 weeks	approx. 12 weeks
Dimension range(s)	DN 100 - DN 200	DN 100 - DN 200; 45° branches in DN 100; 90° sockets as from DN 125	DN 100 - DN 200; 45° bends in DN 100	DN 100 - DN 200; 45° bends in DN 100	DN 70 - DN 150; 90° bends in DN 100	Lines as from DN 100, bends up to 90°
Use, starting from main sewer	with LISY system DN 150 - 600	DN 150 - 1800 with tractor system	with SIDAL system in DN 200 to DN 600	with SIDAL system in DN 200 to DN 600	with SIDAL system in DN 200 to DN 600	up to DN 500, without tractor
Cable length/reach	60 m, 33 m with tractor	Pusher operation: 40 m; flushing operation: 120 m	80 m	80 m	45 m	200 m
Additional functions	Fitting of a cleaning nozzle, not possible with LISY tractor	Installation of a cleaning nozzle; with satellite positioner unit when used from main sewer	Cleaning nozzle, shut-off bellows	Cleaning nozzle, shut-off bellows	Cleaning nozzle	Cleaning nozzle
Recommended improvements	- Cleaning should also be possible with tractor - Installation of front flushing system	- Installation of front flushing system	- Use without shaft entry should be possible - Reduce physical burden for advance and retreat	- Use without shaft entry should be possible - Reduce physical burden for advance and retreat - Increase image stabilization****** - Install rotary/pivoting-head camera****** - Install front flushing system******	- Use without shaft entry should be possible - Reduce physical burden for advance and retreat - Install rotary/pivoting-head camera - Install front flushing system	- Improve film/image quality - Install rotary/pivoting-head camera - Install front flushing system - Reduce physical burden for hose operation
IKT conclusions	Inspection system with high registration quality (system records, pipe diagrams and film/image quality)	Inspection system with freely movable rotary/pivoting head (pivoting of sockets possible)	Inspection system with freely movable rotary/pivoting head and shut-off system (pivoting of sockets and shut-off of side incomers possible)	Inspection system with shut-off system (shut-off of side incomers possible)	Inspection system specifically for extremely small diameters (up to DN 70 in test)	Inspection system with powerful cleaning function (additional side-emitting nozzle inserts are integrated)

The test marks and recommended improvements relate to the applications examined in the test under the selected boundary conditions.
*Evaluation: 100 % of systems entered = 1.0 to 0 % entered = 6.0; depiction of grades using linear function.
**Evaluation: 100 % of repaired/non-repaired damaged points in the system zones entered detected = 1.0 to 0 % detected = 6.0; depiction of grades using linear function.
***Verdict of system operators: 100 points = 1.0 to 0 points = 6.0; depiction of grades using linear function.
****Evaluation: in place = yes; not in place = no; depiction of grades using linear function.
*****System diagrams not submitted.
******This has already been implemented in the development of the Göttingen ZK drain worm 70/500 with rotary/pivoting-head camera.
Evaluation key for test results: Very good = 1.0 to 1.5. Good = 1.6 to 2.5. Satisfactory = 2.6 to 3.5. Adequate = 3.6 to 4.5. Poor = 4.6 - 5.5. Unsatisfactory = 5.6 to- 6.0.
Test report available for download from: www.ikt.de

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Nozzle drop test

Nozzle drop test

The „levitation" of nozzles in the conduit can occur in cleaning of conduits using HP nozzles. The nozzle can, for example, fall onto the conduit wall when water pressure is suddenly reduced. METROMAX PRC GmbH & Co. KG therefore had tests performed with the IKT in order to determine how metromax polymer-concrete pipes react to loads caused by movements of the HP nozzle body.

For the purpose of the nozzle drop tests, the test objects were exposed to various levels of loading using an HP nozzle as customarily used in practice:

1. Dropping of a levitating HP nozzle
2. Lowering and manipulation of an HP nozzle
3. Dropping of a levitating HP nozzle with great frequency

METROMAX PRC GmbH & Co. KG provided the test apparatus and performed the tests. The test procedure was observed and documented by the IKT. The pipes were visually inspected after completion of three load levels. The overall picture presented by the results obtained did not indicate any material abnormalities which might cause impairment of the tightness, strength or correct functioning of the test objects.

Background

It had been established in the context of the IKT „Conduit cleaning: Nozzles, pressures, high-pressure jets" research project financially supported by the North Rhine-Westphalia Ministry of the Environment [1] that nozzles are capable, in exceptional situations, of migrating upward along the pipe wall, and even of „levitating" within the pipe. It is not always possible for the operating staff to avoid, or even detect, this. Dropping of the nozzle onto the pipe wall is then conceivable in case of a sudden fall in pressure. The effects of an individual descent of the nozzle onto the pipe wall were therefore observed within the framework of the above-mentioned research project for twelve different pipe products (see [1]). In addition, the practical experience gained by system operators also indicates that the nozzle body can impact in case of operating errors by the persons operating cleaning vehicles in case, for example, of lowering of the nozzle into the manhole shaft and its manipulation into the conduit.

Test apparatus and load types

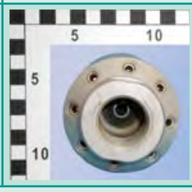
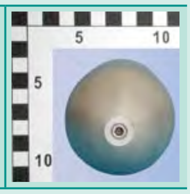
A commercially available omnidirectional nozzle with a weight of 4.5 kg was lifted up to the pipe crown (DN 300) around 50 cm from the pipe joint and then dropped for the purpose of the tests. The nozzle was connected to a rubber DN 32 high-pressure flushing hose, in order to simulate operating practice as authentically as possible. After the descent of the nozzle, the impact surface was examined, and any abnormalities were recorded. Two differing test systems were used, in order to take account of any possible influences exerted by the pipe bedding during the tests.

For the first load stage, nozzle drop tests were performed on eight polymer-concrete metromax pipes. The test parameters of nozzle type and pipe bedding were selected with reference to [1]. The nozzle used conformed to the requirements of DIN 19523 (draft version).

The test parameters selected for the „Dropping of a levitating HP nozzle" load situation and the test program are shown in Table 1 (next page).

Diagram of system showing bedding of metromax pipes in the nozzle drop test

Nozzle drop test on metromax pipes

PRC metromax DN 300 pipes as per DIN 54815	Bedding 1	Bedding 2
Test Pipe 1	5 x drops / 100 x drops*	5 x Fallen
Test Pipe 2	5 x drops / 100 x drops*	5 x Fallen
Test Pipe 3	5 x drops / 100 x drops*	5 x Fallen
Test Pipe 4	5 x drops	5 x Fallen
Test Pipe 5	5 x drops	5 x Fallen
Test Pipe 6	5 x drops	5 x Fallen
Test Pipe 7	5 x drops	5 x Fallen
Test Pipe 8	5 x drops	5 x Fallen
Test nozzle 4.5 kg 8 nozzle inserts 30° emission angle (as per E DIN 19523)		 

* Extreme frequency of a falling HP nozzle as orientational material test, with no relevance to practice

In addition, the loads exerted on a metromax pipe as a result of incorrect insertion of an HP nozzle into the conduit were also simulated in the context of the „Lowering and manipulation of an HP nozzle" load situation. For this purpose, the 4.5 kg HP nozzle was swung energetically into the pipe thirty times from an elevated position.

Incorrect, over-energetic insertion of the HP nozzle into the pipe

No material abnormalities at or around the pipe joint after five-fold dropping of an HP nozzle

The pipes were visually examined for any material abnormalities after application of the above-described loadings, which are authentic and conform with maintenance and cleaning practice.

Results

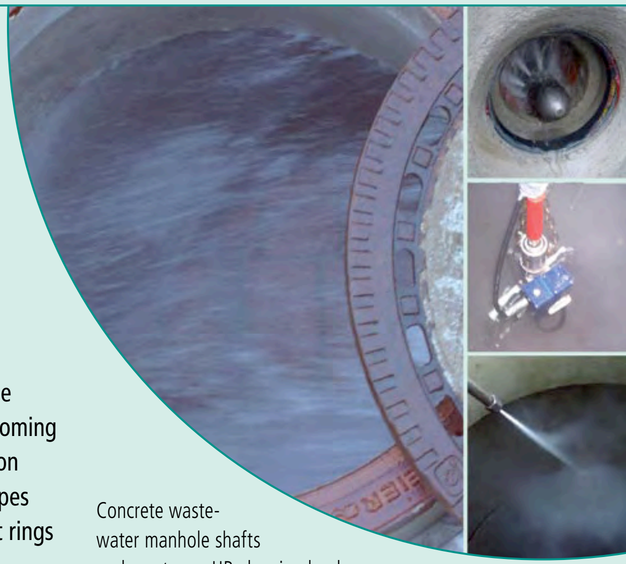
A pulse-like or surging load exerted on the pipe by the moving nozzle body is conceivable in conduit-cleaning practice. The application of extreme cleaning parameters can also, in principle, result in „levitation" of the nozzle body, followed by its falling to the floor of the pipe (if water pressure is suddenly reduced, for example), particularly in case of irregularities in the pipe floor (socket steps, etc.) and nozzle bodies sensitive to movement. The overall picture presented by the results obtained in the tests on loadings exerted on pipes by nozzle movements did not indicate in the metromax pipes used any material abnormalities which might lead to impairment of the tightness, strength and correct functioning of the test objects.

References

[1] Bosseler, B.; Schlüter, M.: Kanalreinigung - Düsen, Drücke, Hochdruckstrahlen, concluding report by the IKT - Institute for Underground Infrastructure on behalf of the Ministry of the Environment and Conservation, Agriculture and Consumer Protection of the state of North Rhine-Westphalia; 2004. Available for download at: www.ikt.de

Source: IKT eNewsletter, April 2008

Concrete manholes under HP-tests



Concrete waste-water manhole shafts under extreme HP-cleaning loads

Throughout their service-lives, conduit construction products are required to withstand considerable loads. The question of suitability for high-pressure flushing is therefore one of the purchasing-decision criteria for system operators. Product tests make it possible to recognize at an early stage any potential risks of subsequent flushing-induced damage during operation. For this reason, Betonwerke Bieren GmbH, of Bad Oeynhausen, Germany, commissioned the IKT - Institute for Underground Infrastructure to perform a systematic test.

The suitability of concrete wastewater manhole shafts for high-pressure flushing

Betonwerke Bieren wished, in the interest of its customers, to determine by means of testing how its manhole-shaft systems and pipes behave across numerous high-pressure flushing and shaft-cleaning operations, even under extreme load conditions. Intensive high-pressure flushing tests, with particular loading of wastewater shaft components and drain/sewer pipes, were therefore conducted at Bad Oeynhausen.

Test program under extreme load conditions

The IKT monitored and observed these tests. The test objects were firstly exposed to loads at three different loading levels. Betonwerke Bieren provided the test apparatus and performed the tests. After the completion of three load stages, starting with conditions approximating to operation and ranging up to the extreme loads encountered during high-pressure cleaning, the pipes and the manhole-shaft joints and connecting points were subjected to visual examination.

Test apparatus and load types

metromax polymer-concrete pipes from Polymer-Kanalsystem GmbH & Co. KG and manhole-shaft components produced by Betonwerke Bieren GmbH from the SD SEAL, TOP SEAL VARIO and TOP SEAL PLUS seal and load-transmission system ranges were used for the tests. The lower shaft section features a DN 250 incoming and outgoing connection with a connection facility for metromax polymer-concrete pipes and a clinker brick channel. The two shaft rings each had a height of 500 mm.

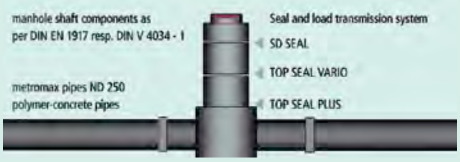


Diagram showing the test apparatus

Test apparatus

Loading Level 1: Cleaning using a HP vehicle approximating to operating practice

The test were performed at Betonwerke Bieren GmbH on February 12 and 15, 2008. The first loading stage consisted of performance of service cleaning of the conduit train and lower shaft section. For this purpose, the test pipe string consisting of the metromax pipes and the lower shaft section was exposed to one hundred cycles of a loading as encountered in everyday practical high-pressure cleaning. The test parameters of nozzle pressure and throughput were selected with reference to the Hamburg Flushing Test. The nozzle used in the test conformed to the requirements of DIN 19523 (draft). The nozzle pressure of 120 bar at the nozzle was checked using a digital pressure gauge.

HP flushing tests, checking of pressure immediately upstream the HP nozzle

Operationally authentic shaft-cleaning – 50 times without interruption

In addition, the loading to which the shaft components and joints are exposed during a shaft-cleaning cycle were also simulated in the context of the „Service cleaning" load situation. For this purpose, a single HP jet from the hand-held cleaning lance of a standard HP cleaning vehicle was held and moved across the shaft walls and the joints at a short distance from these surfaces for a period of twenty-five minutes. The time needed for service-cleaning had previously been determined to be around 30 seconds of pump running time per shaft-cleaning operation. The twenty-five minute exposure time thus represents around fifty shaft-cleaning cycles as conducted under normal operational servicing provisions. After completion of the above-mentioned service-cleaning exposure, the pipes and the shaft components were disassembled and visually inspected for any material abnormalities.

Service-cleaning: Exposure of the pipe length to HP flushing-nozzle loads

Service-cleaning: Exposure of the shaft system to HP hand-held lance loads

Exceptional and special cleaning – involving extra-high pressure

The second loading stage involved performance of an **exceptional cleaning cycle** on the shaft walls and the joints. For this operation, a single HP jet from a special Rotor-Jet nozzle was mounted on a hand-held cleaning lance and passed across the shaft wall and the joints at a short distance from them while emitting a high-pressure jet (200 bar). This exceptional cleaning cycle represents the loading necessary for removal of stubborn encrustations (such as concrete washed into the conduit from construction sites) during shaft cleaning.

The tests for simulation of the loads involved in a **special cleaning operation** were characterized by extreme operating parameters (pressure: 300 bar), which were applied with a special cleaning system and rotary nozzles (TSSR) perpendicular to the shaft wall. This represents, for example, HP cleaning for preparation of the shaft surface prior to coating of the shaft with a protective material.

The following table provides an overview of the load scenarios implemented:

	Method	Load emphasis
Service cleaning		
Conduit section		
	The pipe and lower shaft section were exposed to loads approximating to those encountered in practice by high-pressure cleaning. A total of one hundred cleaning cycles was performed. Nozzle pressure was 120 bar at the nozzle, with a throughput of 320 l per minute.	High-pressure jet from conduit nozzle, nozzle dragging along the pipe floor
Manhole shaft		
	A single HP pressure from a hand-held cleaning lance attached to a standard HP cleaning vehicle is passed at a short distance over the shaft walls and the joints for twenty-five minutes. The time required for normal service-cleaning was determined previously to be around 30 seconds of pump running time per shaft-cleaning cycle. The twenty-five minute exposure period thus represents around fifty shaft-cleaning cycles as performed during normal operational servicing work.	High-pressure jet from hand-held lance
Exceptional cleaning for removal of stubborn fouling		
Manhole shaft		
	A single HP jet from a hand-held lance is passed across the shaft walls and the joints at a short distance from these surfaces while emitting a high-pressure jet (200 bar at the pump). The load is applied by means of a special Rotor-Jet nozzle mounted on a hand-held lance and is characterized by extreme operating parameters (pressure: 200 bar) and represents the load necessary for removal of stubborn encrustations (such as concrete washed in from construction sites) in the context of shaft cleaning.	HP jet from hand-held lance (pressure: 200 bar)
Special cleaning as preparation of substrate for shaft refurbishing		
Manhole shaft		
	This load is characterized by extreme operating parameters (pressure: 300 bar at the pump), which were applied across a large surface using a special rotary nozzle (TSSR) held perpendicular to the manhole shaft wall. This represents, for example, HP cleaning for preparation of the shaft surface for coating with a protective material.	High-pressure jet (extremely high pressure)

Results

After application of the loads representing special and exceptional cleaning cycles, the shaft components were dismantled and the shaft joints, in particular, were visually inspected. On an overall view, no material abnormalities which might result in impairment of the tightness, strength and correct functioning of the test objects were observed after the above-described application of high-pressure cleaning loads.

metromax polymer-concrete pipes

No visible loss of material from the pipes

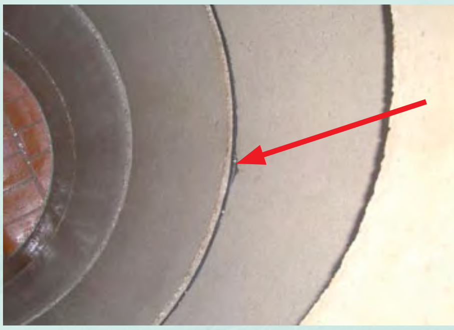
Pipe length: Service-cleaning

After application of service-cleaning loads, no visible material abnormalities were observed on the pipes and the joints.

A loss of material of around 8 mm in depth was observed in the lower shaft section, in the joint from the clinker brick to the pipe connection in each case. This material abnormality does not constitute any impairment of tightness, strength or correct functioning of the test object at present.

Visual assessment of TOPSEAL VARIO

No visible loss of material from the pipe joint



Slight loss of material from the shaft ring
(around 5 mm in depth)

Shaft rings and joints: Service, special and exceptional cleaning cycles

No visible material abnormalities were observed on the pipe joints featuring the SD SEAL, TOP SEAL VARIO and TOP SEAL PLUS sealing systems after application of the loads corresponding to service-cleaning and of the intensive loads corresponding to special and exceptional cleaning cycles.

Material loss of around 5 mm in depth was observed on one shaft ring after intensive special cleaning. This material abnormality does not at present constitute any danger for the tightness, strength and correct functioning of the test object.

It can, **in conclusion**, be ascertained that no material abnormalities which currently constitute any impairment of the tightness, strength and correct functioning of the test objects were observed on the shaft components, joining systems and polymer-concrete pipes used in the tests after exposure to a range of loads resulting from high-pressure cleaning.

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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 about 100 cities, among them Berlin, Hamburg, Cologne and London (Thames Water). They hold together 66.6% of IKT.

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

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

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