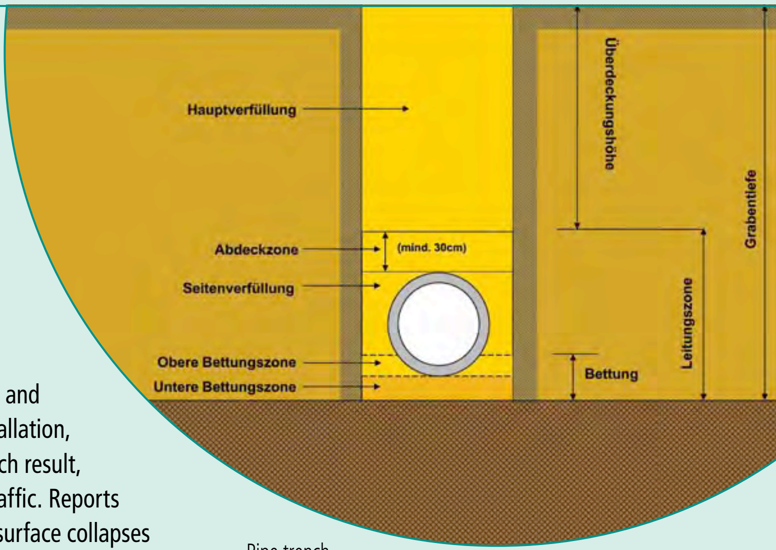
# Pipe and soil are one system




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

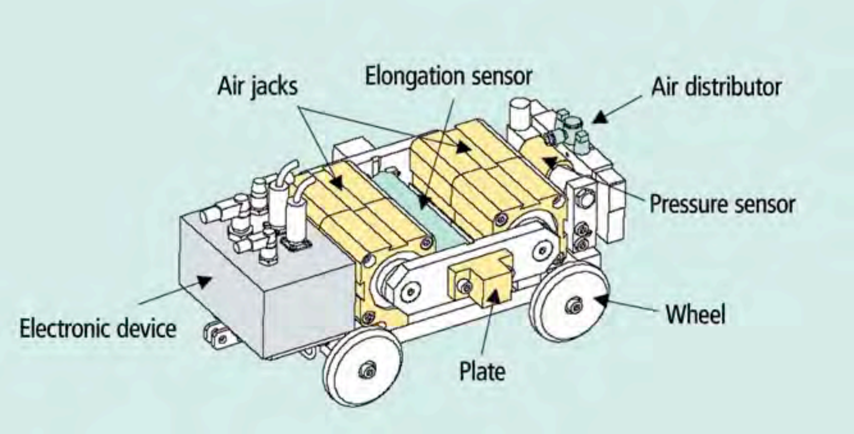
Investigation of the pipe/soil system encompasses determination and recording of the static interactions between the pipe and the surrounding bedding structure. The available measuring systems expose the complete system to a pulse-type physical loading and record the system response for further analytical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

Use of ultrasound for detection of ingrowth of roots




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

„Ovameter“ and inspection vehicle prior to use

Sewer radar system (photo: Rico)

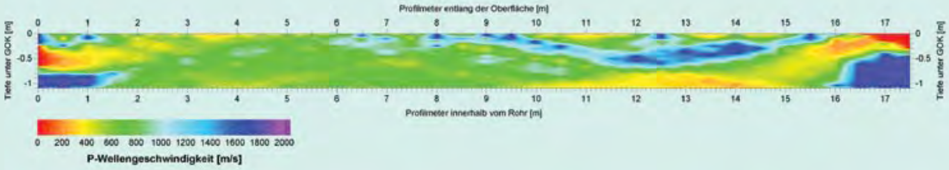
The „Ovameter“ is a mechanical measuring method already in practical prototype use. It involves (see [6]) the application of a defined deformation and the drawing from the force measured of deductions concerning the elastic properties of the pipe/soil system, such as the horizontal bedding stiffness 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.

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

## References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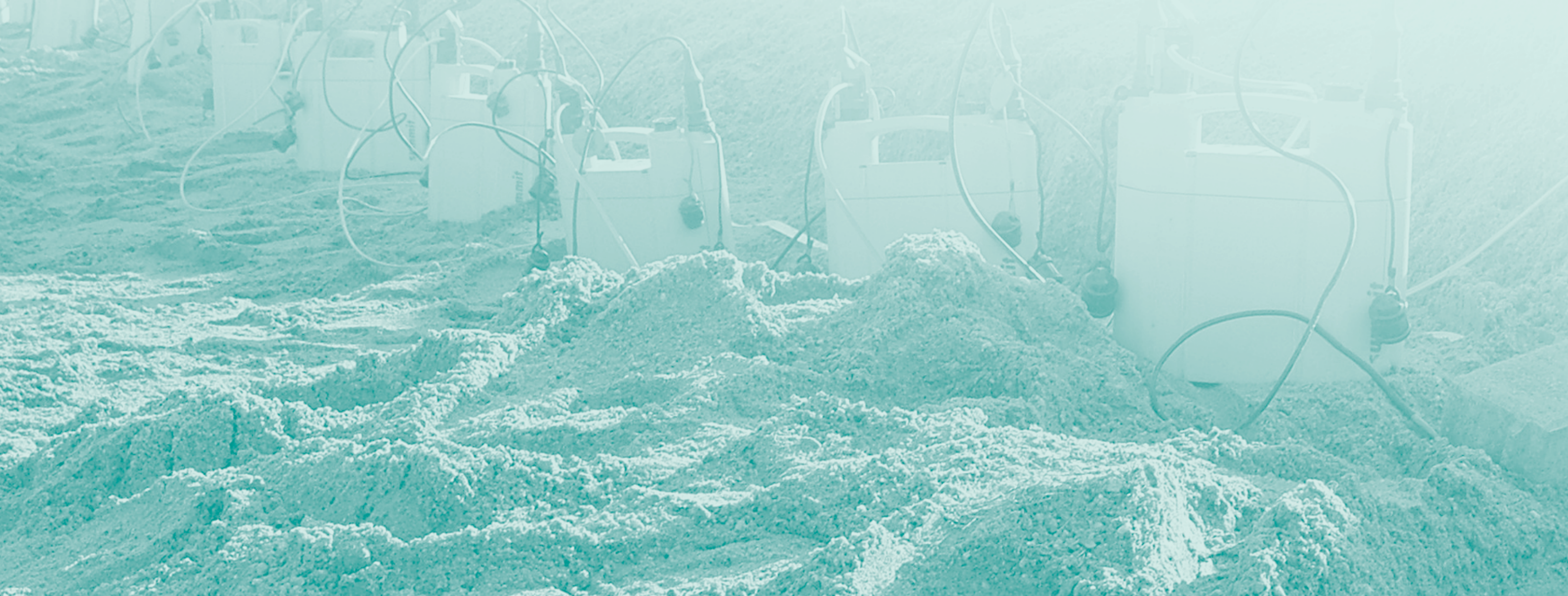

neutral
independent
non-profit institute

IKT - Institute for Underground Infrastructure

# ABOUT IKT

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

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

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

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

**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.

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