Large-diameter drains and sewers: installation, operation and maintenance

Experience from research, quality assurance and comparative product tests

Large-diameter pipes are the backbone of drain, sewer and other conduit systems. Their installation, operation and maintenance confront system operators with great challenges, however. IKT's application-orientated research projects and comparative testing of products and methods assist in achieving better comprehension of the complex interaction between quality requirements and cost-efficiency, in generating new knowledge, and in directly implementing the results in practice. Typical topics include open-trench and trenchless installation, cleaning, inspection, condition assessment and renovation.

Open-trench installation of large-diameter pipes

The installation of large-diameter pipes using open-trench methods makes high demands on work execution and on quality. In addition, reinforced-concrete and plastic components necessitate special knowledge, and profound understanding of specific material behaviour and the necessary quality assurance provisions.

A diverse range of questions arises when significant cracking occurs in large-diameter reinforced-concrete pipes:

- What crack dimensions are acceptable?
- What mechanisms are in fact acting?
- How can such damage be avoided in future?

Cracking is particularly critical if there is a danger of leakage or of consequential damage to the reinforcement. Repair is expensive, and frequently involves drawn out legal disputes between the parties. In order to provide clarity here, the IKT has developed its "Biaxial compression test", a special, highly authentic test for evaluation of the load-bearing and cracking behaviour of reinforced-concrete pipes [1]. The pipe is subjected during the test to the same loading strains as may be anticipated in practical service in the soil.

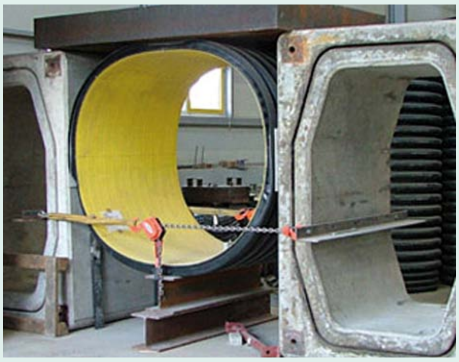
The test applies not only vertical, but also "supporting" horizontal loads. The internal stress patterns in the test cross-section (the crown of the pipe) then correspond exactly to in-situ conditions. It is then possible to evaluate the cracking behaviour of the "composite" material, reinforced concrete, without residual doubt. It would otherwise be necessary to anticipate deviations of up to 100% between the test and practice, even using the same crack-initiation stress in the concrete for the crack width observed.

Biaxial compression test (vertical/horizontal) for authentic testing of large-diameter pipes

As a result, it is possible not only to test and evaluate concrete tensile strength, but also crack propagation and the bonding behaviour between the steel and the concrete. The necessity for at least minimum reinforcement of the "large-diameter reinforced-concrete pipe" component, and the significant improvement in bond behaviour achieved by curing and sealing of the concrete were, for instance, confirmed in numerous tests. In addition, random-sampling testing also demonstrated that the design conditions normally selected for reinforced-concrete pipes need to be questioned in terms of concrete coverage and the spacing of the layers of reinforcement. On an overall view, the new test system provides additional safety for the optimisation and evaluation of large-diameter reinforced-concrete pipes.

Large-diameter plastic pipes are, in addition, also increasingly coming into use in drain/sewer construction. These types offer high flexibility, are relatively light, can, at least, be welded, and are generally resistant to aggressive media. Many operators encounter uncertainty when the flexibility of such easily deformed pipes gives rise to doubts concerning the stability of the structure in certain cases, however. The IKT has therefore also developed for these pipes practically orientated test concepts, which provide additional safety both in the laboratory and on the site [2].

It is thus now possible to investigate and evaluate the behaviour of large-diameter plastic pipes under exposure to deforming conditions in short-term (24 h) tests. In a similar manner to the testing of large-diameter reinforced-concrete pipes discussed above, not only vertical loads, but also horizontal bed reactions, are simulated in a special test apparatus. In this case, typical deformation states relevant in practice are induced in the pipe, and evaluated for the stability of the overall cross-section, the wall profiles and the welds. The crown and the bottom abutments can be equipped with load cells, and deformations maintained across a longer period, in a rigid load-application frame, where it is intended to register additionally the relaxation behaviour of the pipe under deformation, which is typical of plastics.



Large-diameter plastic pipe undergoing long-term relaxation testing

The methods for in-situ registration of pipe deformations have also been further developed, as the geometrical shape of the deformed pipe to be recorded is generally not known in advance, and the use of the necessary measuring technology always involves considerable work and complexity. The deformations are then visually and metrologically registered during a conduit inspection, evaluated with respect to external boundary conditions (live loads, bed material and surface buildings) and more extensive investigations proposed where appropriate (e.g. time-dependent deformation checks).

Studies performed up to now on large-diameter plastic pipes confirm the special significance of the quality of installation for the stability of the overall pipe/bed system. Not only cross-sectional deformations, but in many cases also horizontal/vertical displacements and, in a few instances, local deformations, are observed. In addition, the evaluation of stress-analysis calculations for completed projects also indicated that extremely optimistic assumptions had been made for soil conditions and degree of compaction. The available strength reserves are also generally fully utilised, particularly in the deformation and stability analyses. The importance of the formal acceptance inspection and of periodic inspection during operation thus becomes even greater. A combination of optical inspection and measurement of deformation is recommendable for the

In-situ measurement of deformation in large-diameter plastic pipes

detection and registration of abnormalities, in order to obtain informationally useful inspection results. Critical zones can then be delineated and shorter inspection intervals assigned for them.

No-dig installation: pipe jacking

Trenchless ("no dig") methods employing pipe jacking have proven suitable as an alternative to the installation of new large-diameter pipes using the open-trench procedure. Here, the pipes are subjected to special loads, particularly where the routing is not straight, and in case of difficult soil conditions. Inspection concepts developed up to now have, however, been restricted to the inspection of individual pipes and joints, and have ignored the curvature and bedding of the pipe string. A test system, using which pipe-jacking loads exerted on pipes and pipe joints can be simulated, complete with the resultant bed stresses, on a 1:1 scale, has been developed at the IKT, in the form of the IKT pipe-jacking simulator [3]. Recommendations for the optimisation of pipe joints, for the planning and control of pipe-jacking operations, and for on-site metrological support, have been derived from the test results.

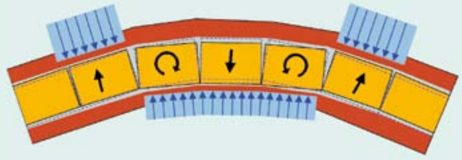
IKT DN 2000 pipe-jacking simulator: jacking pit 8 MN

The concept of the IKT pipe-jacking simulator augments the "passive" concept of measurement of a pipe exposed to external loads with an "active" observation element: when passing through curves , the longitudinal force necessary for jacking also generates a transverse movement of the unrestrained pipe string into the bed, with the result that corresponding bed reactions are activated. This special behaviour of the pipe string is simulated on a 1:1 scale in the IKT pipe-jacking simulator. Various means of force transmission into the pipe joint can be used, and various routing elements, such as curves and control movements, traversed repeatedly during simulation.

The geometrical and mechanical properties of the particular pipe-jointing technology demonstrated their special effect during the test. The magnitude of the bed reactions varied according to the routing and the selection of the (calculated) bore diameter oversize. The "ideal kinematics" of a curved pipe string generally assumed in the structural design, i.e., uniform distribution of pipe angling across all the pipes, were disproved. Individual groups of pipes have a tendency to "go straight on", with the result that greater degrees of angling must be expected at another point.

Passage through curves must therefore be regarded as a critical pipe-jacking state in terms of the loads exerted on the individual pipe joints, since heterogeneous degrees of angling also result in heterogeneous bed reactions and in significant transverse-force effects. The pipe loads to be anticipated are then essentially determined by the (non-linear) properties of the means of force transmission. The following provisions for quality assurance are therefore proposed:

16 m pipe string consisting of five DN 2000 test pipes in a bed structure consisting of positionable steel rings with hydraulic cushions

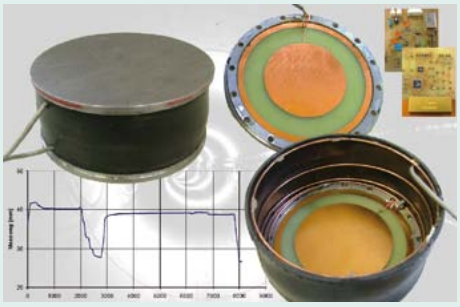


Pipe jacking, test result for passage through a curve: heterogeneous bed reactions with extreme angling between individual pipes

The materials characteristics data for the means of force transmission definitive for pipe-jacking should be determined at the planning stage and checked during pipe-jacking operations. Control specimens should be kept for the purpose of special tests in critical jacking situations. Quality Assurance for the jacking pipe can also be initiated prior to the start of production; the production conditions can be checked at the manufacturer's works and geometries and finished products measured at the works and on the site. Random-sampling-based quality tests under authentic loads (see modified vertical compression test) are also an available option, particularly in the case of special constructions and where increases in loads at a later time can be expected.

The pipe string should be visually inspected at suitable intervals during installation, in order to detect any abnormalities and permit the initiation of corrective action. Distributed metrological inspection of pipe joints during installation (using a slide gauge, for example) can also supply important information on the load exerted on the pipes and assist in locating critical zones, with a view, also, to the formal acceptance inspection. The IKT is, in addition, currently testing a measuring system integrated directly into the means of force transmission for measurement of joint-gap width, employing wireless transmission of the measured data. This eliminates the hindrance of on-site work by measuring instruments and cables, and significantly enlarges the number of joints measured.

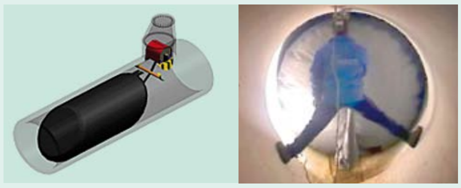
The research topic of "pipe jacking" continues to fascinate. There are, in practice, still numerous questions concerning planning, design, implementation and acceptance which require clarification. This is also true of the use of special cross-sections, such as rectangular-section pipes [4], which are also being tested in 1:1 scale experiments at the IKT.



On-line measurement of joint-gap width: measuring instrument

Use of the measuring instrument during pipe jacking

Rectangular jacking pipe: the insertion pit in the IKT large-scale test facility



Left: Surge-flushing using the flushing bag: system diagram (HST) Right: in use in the IKT test sewer

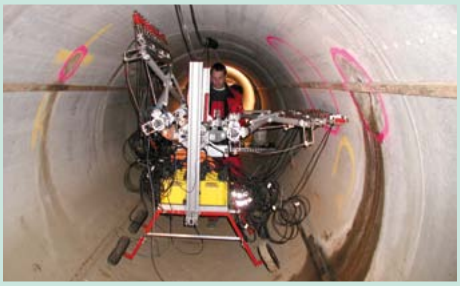
Cleaning and inspection

High-pressure flushing is the method most frequently used in practice for conduit cleaning. It runs up against its technical and economic application limits in the case of the cleaning of large conduits, however. Surge-flushing methods are an alternative, but have up to now required extensive civil-engineering provisions, and therefore the willingness on the part of system operators to invest large sums. In view of the ever-increasing economic pressure, still more solutions are needed, in order to achieve the necessary cleaning performance at rational cost.

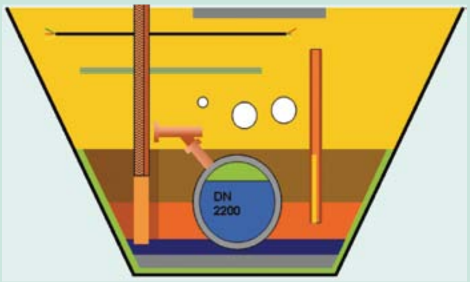
This opens the way for an innovative equipment development, known as the "flushing bag", and tested at the IKT [5]. For use of the "flushing bag", water is firstly dammed up, and then suddenly released into the conduit in the form of a "surge wave", to clean the conduit. The device can be integrated into existing manhole structures, with the result that no extensive new structural work is necessary.

Alternative inspection methods have also been investigated at the IKT. Large conduits, in particular, are frequently subjected to heavy loads, and continuously conduct large flows of sewage. For many system operators, the question arises, for these permanently partially filled sewers, of "How can such conduits be inspected in operational state?". The IKT has investigated various methods for inspection of partially filled large-diameter conduits in a pilot project [6]. The aim here was that of providing the responsible engineer with general information for the preparation of inspections and for the planning of future systems to take the necessity of inspections into account. The investigations involved both the selection of the most suitable inspection system or method, and the preparation of supplementary provisions to support the inspection procedure, such as drainage and conduit cleaning. More detailed information on the inspection of large-diameter conduits has been compiled by the major German system operators in Berlin, Hamburg, Munich and Cologne, and the Ruhr region's Emschergenossenschaft in co-operation with the IKT and has been published in special "Supplementary Technical Contractual Conditions" for "Inspection of large-diameter conduits > 1200 mm" (www.ikt.de/down/11_04_ztv-inspektion-grossprofile.pdf) (German version).

Geophysics in the large-diameter conduit:



Seismics under test



3D-mapped test length, diagram

Length prior to covering

Condition assessment and renovation

The selection of a cost-efficient method for the repair/renovation of large-diameter waste-water conduits and pipes necessitates the obtainment of further, comprehensive information on the condition of the pipe/soil system; such information cannot generally be supplied by means of visual inspection or distributed soundings alone. Geophysical measuring methods provide a rational augmentation here. Anomalies, bed defects and cavities in the vicinity of the conduit, and also defects in the pipe body, can be detected and integrated into the assessment, to permit appraisal of the stability and damage level of a structure.

Various geophysical methods, such as seismics, ground-penetrating radar, ultrasonics and impact-echo, have been scientifically investigated and tested under authentic conditions in a special IKT test length [7]. Seismic tomography, in particular, permits the derivation of extensive information on the condition of the soil between the terrain surface and the conduit. It is possible, in principle, to detect and locate cavities, non-homogeneous soil conditions and underground rubble, etc., in the vicinity of the conduit. Many measuring methods encounter their application limits when approaching the groundwater, however. In addition, the success of a measuring campaign using geophysical methods depends on the extent to which a measurable difference exists between the physical properties of a fault zone or anomaly and those of the other, comparatively undisturbed, zones. In the case of measurement in the interior of a waste-water conduit, the measured result can, in addition, also be significantly affected by the pipe material. On an overall view, the inspection of conduits using geophysical methods also necessitates special technical know-how, extending from planning and execution of the measurements, up to and including interpretation of the results.

As far as the actual civil-engineering renovation of large-diameter profiles is concerned, system operators are ultimately also obliged to substantiate their renovation decisions with reliable structural analyses. This becomes difficult when, in the case of older waste-water conduits, for example, scarcely any information is available on the original structural design, on soil quality in the vicinity of the pipe, and/or on the wall structure of the damaged waste-water conduit. Eau de Paris, in France, has therefore developed a non-destructive test method designated “MAC”, which supplies, by means of force/deformation measurements, reliable information on the stiffness of the pipe/soil system, and thus provides the basis for reliable assessment of stability [8]. The IKT is currently further developing this system, with the result that direct structural assessment of large-diameter profiles will in future be practicable for nominal diameters of greater than DN 800. It will then be possible to register and evaluate both the original and the current condition of the renovated conduit in a kind of “before-and-after” appraisal.

The MAC system (Eau de Paris) for assessment of the stability of large-diameter profiles (photo: Eau de Paris)

International “Large Pipes and Sewers” network

Large-calibre pipes and waste-water drains form the “backbone” of the underground infrastructure. The construction, operation and maintenance of these systems confront system operators with great challenges, however. The “LARGE PIPES AND SEWERS” network organised by IKT now provides all operators of large-calibre conduits and pipes with a platform for interchange of knowledge and experience, the aim being that of preparing and substantiating even difficult investment and operational decisions on the basis of exchange of experience with other major operators. The participants’ experience is to be systematically compiled, prepared, discussed and jointly evaluated for this purpose. Every participant will thus benefit from the knowledge and experience of the network as a whole. Workshops are to investigate and broaden conceptual solutions for typical engineering and operational questions, concerning, for example, tendering and award-of-contract procedures, and also quality assurance in the context of large-diameter pipe projects. The IKT is, in addition, also drafting market surveys and organising visits to sites and companies. Participants will thus obtain well-founded technical information from a neutral and impartial source. Further information: www.large-sewers.org

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ABOUT IKT

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

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

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

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

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

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

You can find information on projects and services at:
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