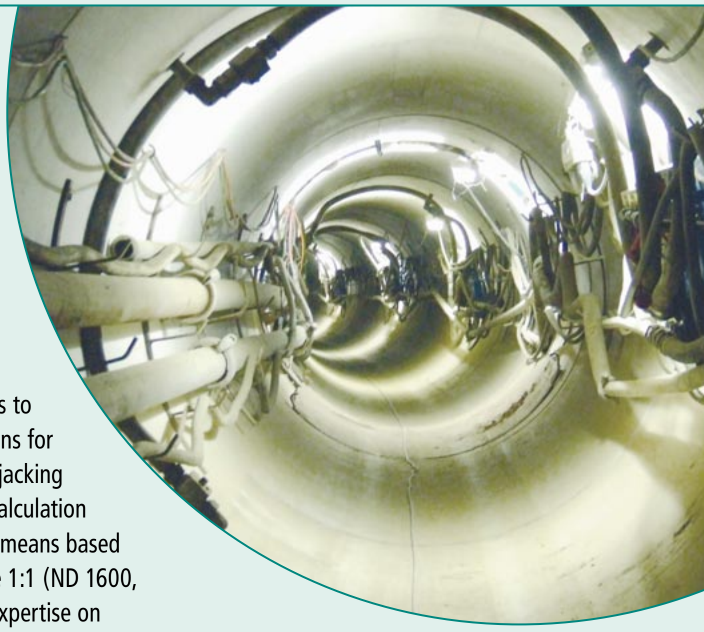
Quality assurance in pipe-jacking



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

Test equipment

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

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

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

Figure 1 jacking simulator ND 1600 with side hydraulic cylinders

Focus of action

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

Planning

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

Components and materials

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

Construction

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

◉ Building and guarantee acceptance

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

Planning

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

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

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

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

Component and materials

◉ jacking pipes

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

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

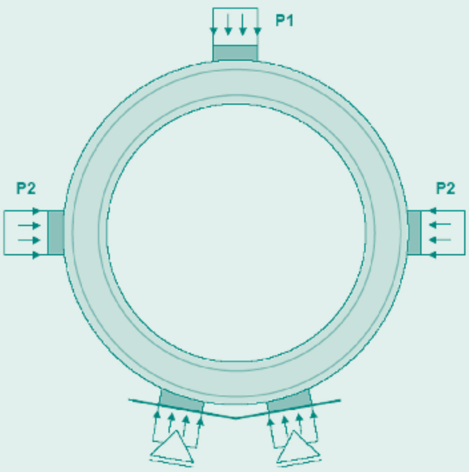
Within the project framework, the IKT researchers dealt with dimensions and dimensional tolerances for jacking pipes. Here it appeared already before production start that measurement of the pipe form could be meaningful in order for example to cover system-related geometry deviations. Furthermore, pipes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

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

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

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

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



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

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

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

- Pressure transmission device

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

Construction

In contrast to new construction in open method of building, the possibilities of client's influence on the quality of the building already seem exhausted at the start of design. From the results of optical inspections, measurement of the pipeline as well as analysis of the pre-jacking forces,

a) Improper support of the pressure transmission devices

b) Dirt of a gaping joint in the sole area

Figure 3 Striking features during visual inspection

conclusions on the condition of the building can always be drawn. Thus, continuous recording of forces on the main and intermediate stations is indispensable. Also at least when lubricant is used the injected quantity and pressure should be recorded time-dependently. In addition, the possibility exists to use more complex, partially automated systems, which can precisely allocate quantity, pressure, and location for jacking.

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

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

Visual inspection

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

Local measurement

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

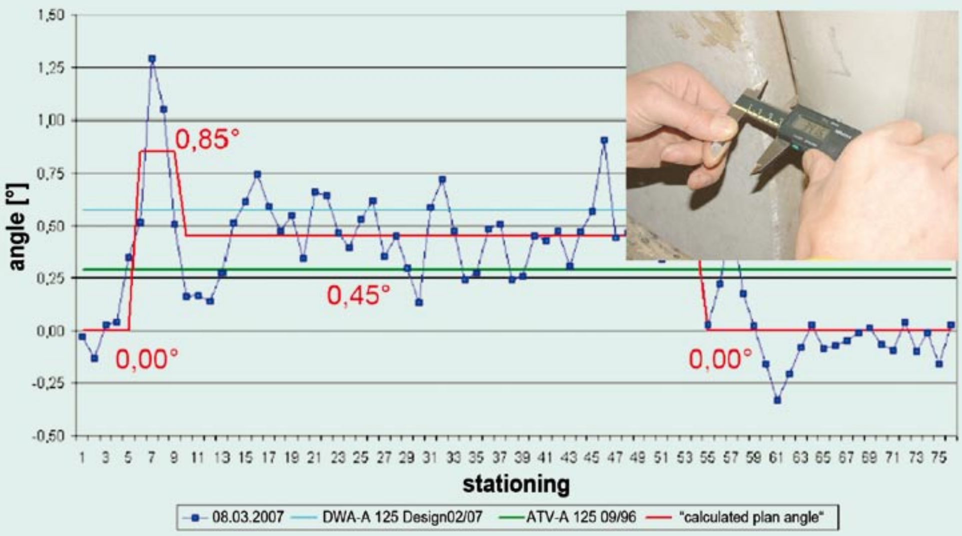


Figure 4 Measurement and corresponding analysis of the joint gap width with a slide rule

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

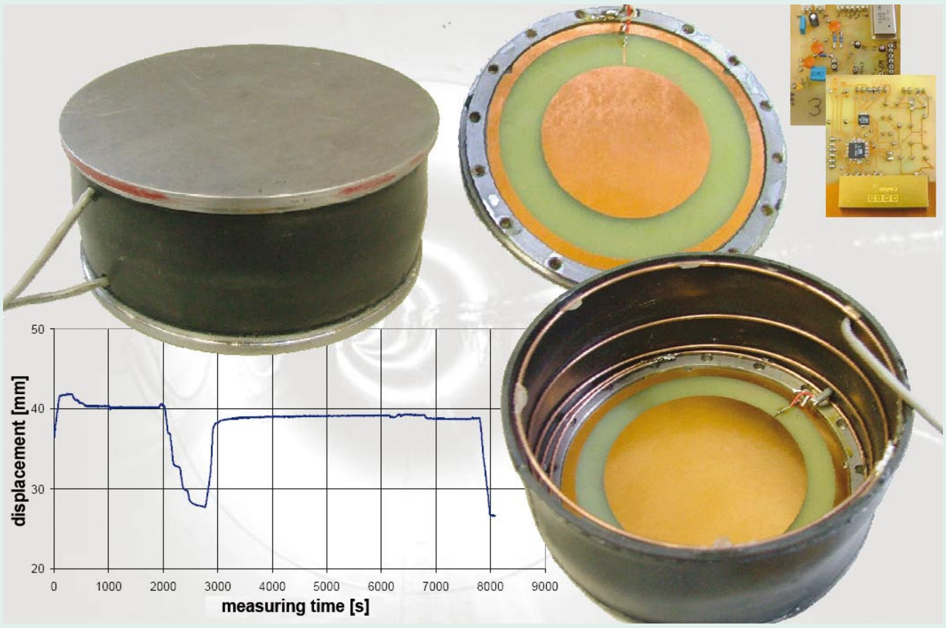


Figure 5 Design of the deformation load cell

Continuous measurement

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

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

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

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

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

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

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

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

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

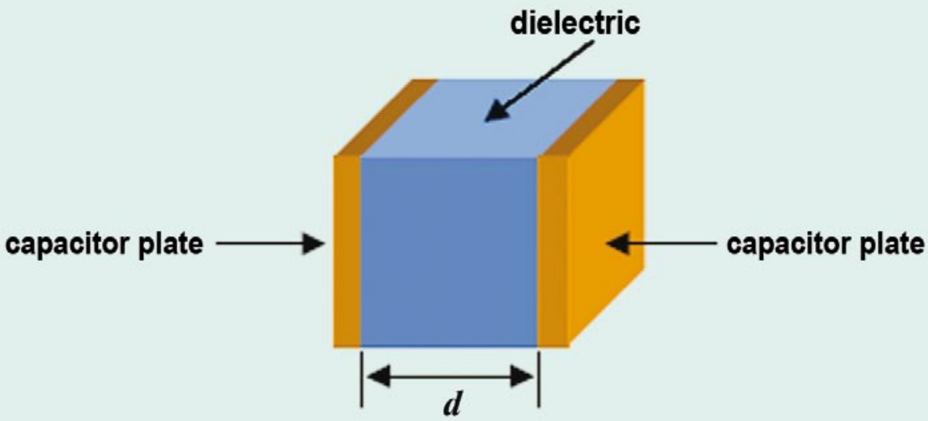


Figure 6 Functioning principle of the deformation load cell

Construction acceptance

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

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

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

Conclusions

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

- The material characteristic values decisive for jacking of the pressure transmission device should be determined already in the planning phase. Tests to guarantee constant quality should be carried out in accompaniment to jacking. Check samples should be held in supply for special tests in critical jacking situations.

- The quality assurance of the jacking pipes can already start before production starts. In this way, the production conditions in the works can be reviewed and forms, finished products in the works and on the construction site can be measured.

- Reinforced concrete pipes are measured always for the individual case. Quality test under near-reality loads as random samples are suitable particularly in special constructions and expected load increases.

- At suitable intervals, the pipeline should be appraised optically in order to recognize striking features and to be able to take correction measures.

- The construction accompanying measurement of all pipe joints, for example with a slide rule can deliver important hints to pipe stress, and can localise critical areas with view of construction acceptance.

- A measuring system integrated directly in the pressure transmission device for joint gap width measurement with wireless transmission of the readings is presently being tested in practice by the IKT. Hereby, especially the obstruction of construction process should be minimised by means of measuring instruments and the number of measuring joints be increased.

- With the help of continuous joint measurement, the entire deformation and thus the loading history can be understood. It is possible to react immediately to critical situations. In cases of doubt, the current actual condition and available reserves can be determined with the help of reference sample of the pressure transmission device. Mathematically, this is possible only to some extent owing to complex material characteristics.

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

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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:
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IKT is located
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Published: September 2010
Circulation: 3.000 copies

Protective charge: 19,95 €