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JACKING OF PRECASTED RECTANGULAR REINFORCED CONCRETE PIPES

The steered jacking of circular pipes for installation and renewal of sewer systems has reached a high technical level in the past few years thanks to international research and development work and presents a tried-and-tested alternative to open trench methods these days. The jacking of pipes with rectangular cross-sections has been limited to little construction work so far, due to cases of damage [1, 2]. Nevertheless the use of rectangular cross-sections can bring considerable technical and economical advantages, e.g. where there is low coverage [3], the construction of rain water retention pipes or the planning of multifunctional collectors [4].

To reach the benefits of this field of application, the Ministry for the Protection of the Environment and Nature, Agriculture and Consumer Protection of the state of North Rhine-Westphalia commissioned the Institute for Underground Infrastructure (IKT) with the development and testing of an innovative reinforced rectangular concrete pipe for pipe jacking in the accessible nominal size. The possible applications for such pipes are to be increased and damage during constructional work avoided.

The complete programme is divided into 3 phases:

Phase I:	Development and testing of a pipe prototype (1998-1999)
Phase II:	Technical optimisation and adaptation of the prototype on the basis of jacking trials on a 1:1 scale (2000-2001)
Phase III:	Pipe jacking under in situ-conditions (pilot project, 2002-2003)

The following reports on the results of Phase I and the boundary conditions of the trials carried out in Phase II. The optimisation and trial phase was characterised by the close cooperation with specialised companies, operators and associations.

In Phase I the development, construction and testing of a pipe prototype were at the fore [5]. Main focuses were placed on the optimisation of the

- shape of the internal cross-section,
- design of the pipe connection,
- means of stress transmission,
- sealing material.

It became clear that considerable constructional modifications to the pipe connection were necessary in comparison to jacking pipes with a circular cross-section. Thus for example both, rebated joints and steel guide rings, did not fulfil static requirements. A new pipe connection was developed as an alternative using the following construction elements :

- Plain butt ends of the pipe
- Steel guide ring no longer used
- Transmission of the lateral forces through steel bolts
- Arrangement of a seal in the centre of the pipe wall

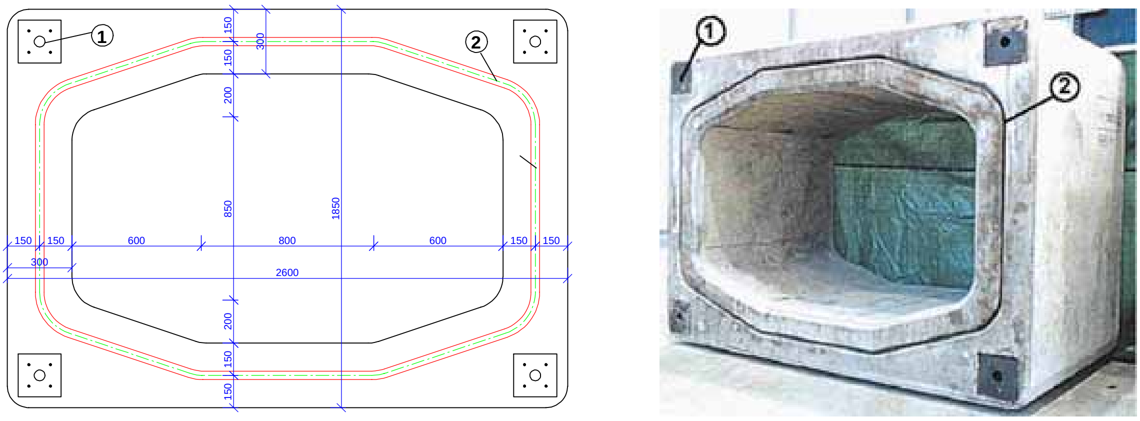
- Two-part stress transmission ring,
- Means of stress transmission as “sandwich construction”.

The static analysis of the pipe walls and the construction elements was carried out on the basis of the following assumed loads (cf. ATV-A 161 [6]):

- Length of jacking: 100 m (without intermediate pressing station)
- Jacking force: 14 MN
- Minimum coverage: 1.5 m
- Maximum coverage: 6.0 m
- Live load: UIC 71 (railway load)
- Maximum level of groundwater: 10 m above the pipe crown
- Eccentricity of the jacking force: Core area

Where bedding is missing in some places for single pipes the lateral force bolts completely accept the vertical forces from the ground, the live load and the weight of the pipe. The distribution of the lateral forces in the overall cross-section is supported by haunches.

Taking the above-mentioned boundary conditions and loads as a basis, the dimensions of the cross-section represented in Figure 1a) were selected and appropriate pipe prototypes with different types of seal were produced. Subsequently the functional ability of the pipe connections was investigated by means of stress and waterproof checks on a 1:1 scale and the pipe prototype illustrated in Figure 1b) was selected.

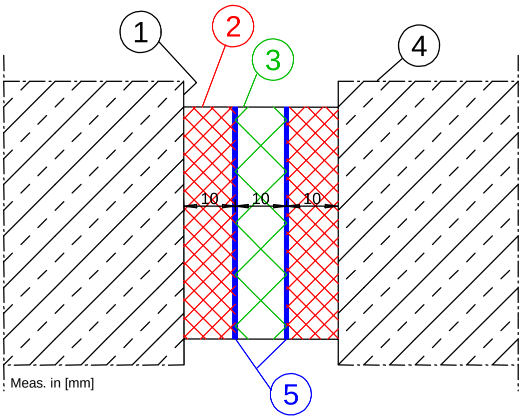


① Sleeves to retain the steel bolts
② All-round groove for retaining the seal

a) Dimensions of the cross-section ***b) Body of the pipe***

Figure 1 Pipe prototype

Laboratory investigations for the selection and testing of the means of stress transmission showed that in this case of application the usual materials chipboard and solid wood can only be used to a limited extent. The large plastic deformation shares in particular prevent a lasting, smooth load discharge, since load cycles resulting from control movements or cornering particularly towards the edges of the rectangular cross-section can lead to uncontrollable stress peaks. In contrast, the elastic deformation shares were able to be increased in a newly developed “sandwich construction” (s. Figure 2), consisting of chipboard on the outside, with a sheet steel and polyurethane core, allowing the well-known advantages of wooden materials (low lateral strain, compensation of unevenness) to still be able to be used.



① Butt end of the pipe
② Chipboard (10 mm)
③ Polyurethane core (10 mm)
④ Reinforced concrete jacking pipe
⑤ Sheet steel (0.2 mm)

a) Basic sketch

b) View of the means of stress transmission

Figure 2 Structure of the “sandwich construction”

For the pipe connection, three innovative sealing systems were initially developed, produced and subjected to extensive tests to make sure they are waterproof on the basis of DIN 4035 [7] (0.5 bar internal pressure) or the FBS quality guideline [8] (1.0 bar internal pressure) (s. Figure 3). Supplementary comparative measurements using air pressure and partial vacuum confirmed the results. Two plug seals and an integrated seal were tested. All the versions tested seemed to be basically suitable for the present case of application. The choice was finally made in favour of the connection construction represented in Figure 4 which uses a plug seal, since this – in comparison to an integrated seal – showed considerable advantages in production and handling.

a) 3 pipe test

b) Joint test: external pressure

c) Joint test: internal pressure test

Figure 3 Tests of tightness

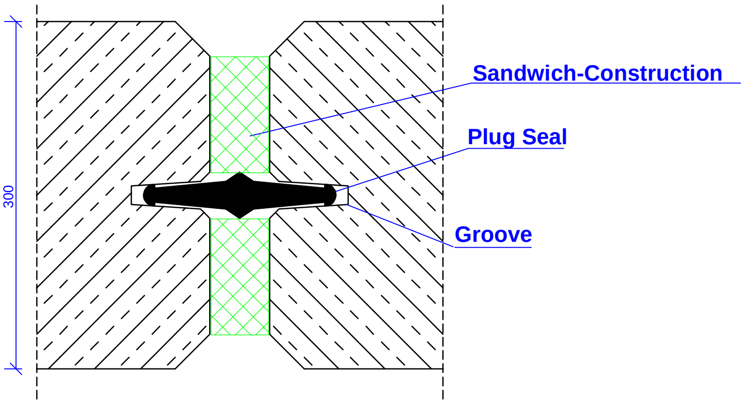
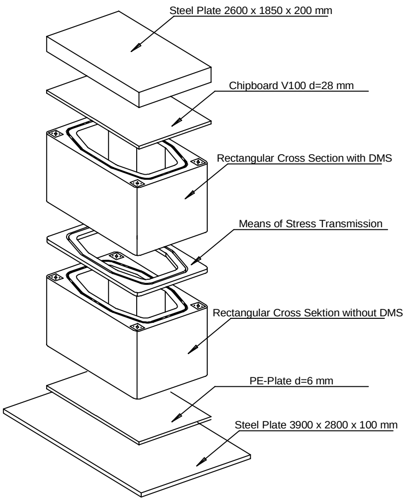


Figure 4 Basic sketch of the sealing system chosen

The pipe concept was tested in loading tests axial and lateral to the pipe axis to see whether the static requirements of pipe jacking are fulfilled. To do this the load transmission in the butt ends of the pipe, shear deformation and shear load as well as the mobility in the pipe connection were recorded at up to 140% of the calculated jacking load (1.4 x 14 MN). Figure 5 illustrates the structure of the axial-eccentric load tests.



a) Basic sketch of the test structure

b) Pipe test

Figure 5 Axial-eccentric load tests

At the moment jacking tests are being carried out at IKT on a 1:1 scale (Figure 6 and Figure 7). An important goal is the observation of the pipe-soil interaction, the demands resulting from this, the failure patterns to be expected as well as any technical difficulties that occur and the effect of protective measures (s. Figure 8). Main emphases are placed on the points:

- Rolling,
- Vertical dynamic loads,
- Penetration of ground material in the area of the pipe connection and the arrangement of protective metal sheets,
- Restraints due to control movements and changing soil stratums
- External water pressure and suspension pressure from Bentonit lubrication.

Figure 6 Large format test stand at IKT for tests on a 1:1 scale

Figure 7 View into the starting pit of the test stand
(external dimensions of the pipe 2.6 x 1.85 m)

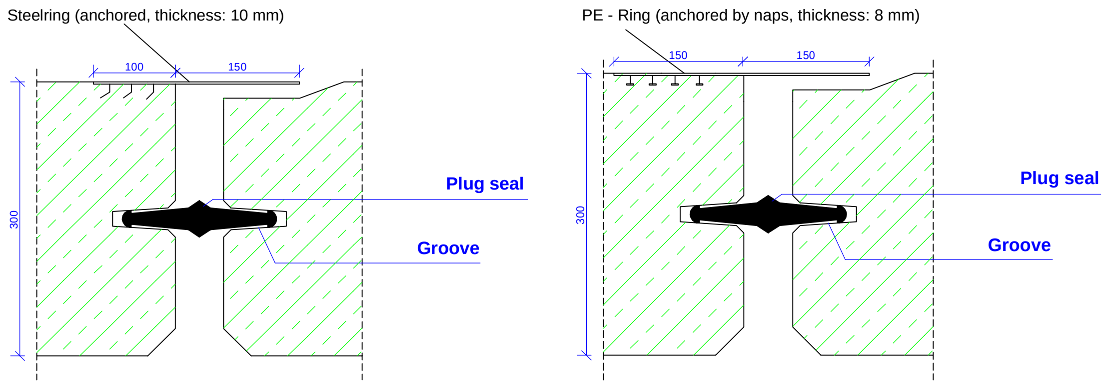


Figure 8 Version of the rings for protection against soil penetration

The soil structure was selected for the test according to Figure 9. Different coverages were able to be simulated during the test using hydraulic pressure pads and dynamic working loads through a hydraulic cylinder (1000 kN) on the surface of the soil (Figure 10).

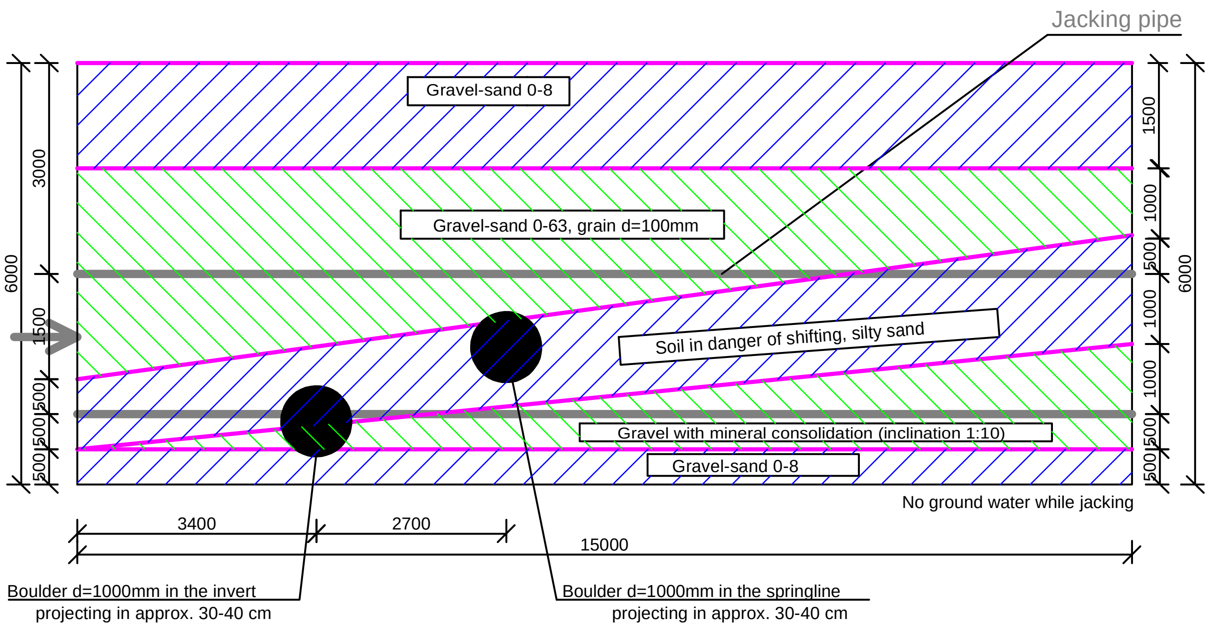
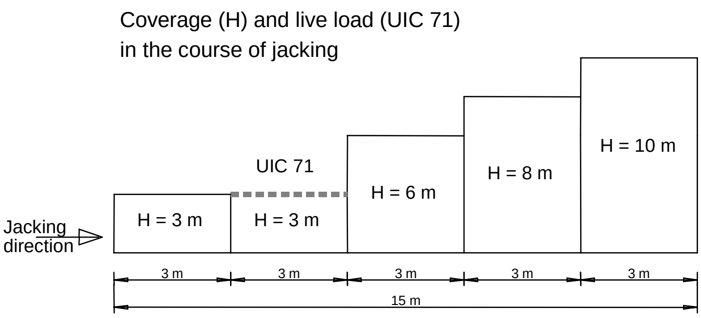


Figure 9 Soil structure for pipe jacking at IKT

a)


b)


a) Simulated coverages and live loads in the course of jacking
b) Hydraulic cylinder for dynamic loads

Figure 10 Static and dynamic loads

The extensive technical equipment required for the measurements accompanying the tests for the main factors influencing the above-mentioned phenomena have to be emphasised. The following equipment was used:

- **Measuring technology in the jacking pipe (**see also Figure 11**)**

(1) 2 rope distance sensors for determining the progress of jacking
(2) 4 distance sensors for each pipe connection for measuring the width of the joint
(3) 3 distance sensors for each pipe connection for measuring the rolling
(4) 1 pressure sensor for recording the injection pressure of the Bentonit lubrication in pipe 6
(5) 2 pressure transducers for measuring the reaction pressure on the Bentonit lubrication on the outside of pipe 6
(6) Foil pressure sensors for determining the distribution of the jacking load between pipe 4 and pipe 5
(7) Target board for the laser (Figure 11)

(1) Face (2) Rope distance sensors (3) Target board (4) Distance sensors

Figure 11 View into the pipeline with the measuring technology installed

- **Measuring techniques in the testing soil**

Measurement cross-sections were arranged for the jacking lengths 1.5 m, 4.5 m, 7.5 m, 10.5 m and 13.5 m. The following sensors were used in each of the measurement cross-sections:

(1) 5-fold inclinometer for recording horizontal soil displacement (overall length: 2.5m).
(2) 5-fold extensometer for recording vertical soil displacement at heights of 1.5m, 2.5m, 3.5m, 4.5m and 5.5m.
(3) 6 earth pressure transducers for measuring vertical and horizontal soil stresses (1 earth pressure transducer above the pipe, 1 earth pressure transducer under the pipe, 2 earth pressure transducers to the right of the springer and 2 to the left).

Figure 12 Soil installation

- **Further measuring technology**

(1) Load and displacement of the 4 steering cylinders
(2) Load and displacement of the 4 main cylinders
(3) Load and displacement of the load cylinder for recording the simulated dynamic traffic load
(4) Pressure in the hydraulic pressure pads for recording the simulated coverage (3 pressure sensors)
(5) Measurement of ground water pressure (1 pressure sensor)
(6) 3D-measuring system TOTAL [9] for recording the position of the pipeline conduit in an intermediary condition and at the end of jacking

The excavation of the soil at the face is carried out by hand. The automatic methods already used for jacking using rectangular cross-sections in Japan [10] were not used, since they are still at the development stage and not available in Germany at the moment. Their use is not worthwhile for such a short jacking distance since they mainly serve to speed up soil excavation. In the meantime the jacking has been completed. Currently various groundwater levels and traffic loads are being simulated and the pipe connections checked to make sure they are watertight.

Conclusions and outlook

The development of a pipe connection for jacking pipes with rectangular cross-section has been confirmed in laboratory tests. New developments, such as the division of the pressure transmission ring, the "sandwich construction" of the means of pressure transmission and the sealing constructions can also provide impulses for the further development of jacking pipes with a circular cross-section. Once the tests on the pipeline conduit laid by the trial jacking process has been completed this will be exposed and subjected to an optical inspection. Appropriate results are expected in Spring 2002. The subsequent test within the framework of a pilot project is being planned at the moment. The focus of further investigations will be in the practical implementation of the jacking technology developed and the investigation and quantification of cost-benefit advantages.

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