A Steel-Cased Pipe-in-Pipe Siphon for Crossing the Major Amsterdam Rijnkanaal Waterway

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Starting from the situation which led to the construction of the steel-cased pipe-in- pipe siphon, the author describes the concrete problems that FW-FERNWÄRME-TECHNIK GmbH faced. Then the technical solutions that were worked out are presented. Next, the author gives an insight into the manufacture of steel-cased pipe-in-pipe systems and reports on their installation on site. Finally, further areas of application for the FW steel-cased pipe-in-pipe system (FW-STAHLMANTELROHR®) are indicated.

Summary of the report:

A Steel-cased pipe-in-pipe siphon for Crossing the Major Amsterdam Rijnkanaal Waterway

For the supply of heat to Amsterdam Zuidost a high temperature water pipeline is being constructed, which is designed to transport a heat capacity of 380 MW. The pipeline is constructed predominantly of ABB plastic-cased pipe-in-pipe. However, for crossing the major Amsterdam Rijnkanaal waterway, which traverses the route, steel-cased pipe-in-pipe siphons are used. This is necessary because laying takes place in organogenic foundation material and the pipeline is subject to exceptional forces, especially in the siphon region, which exceed the stress limits for plastic-cased pipe-in-pipe systems. Correctly designed steel-cased pipe-in-pipe in contrast can also withstand exceptional stresses.

A further benefit of steel-cased pipe-in-pipe is their virtual prefabrication. Individual construction units are provided ex factory with all shaped pieces such as bends, fixed points etc., so that assembly at site is restricted to joining constructional units.

After the individual constructional units had been assembled on the shore to a complete siphon each for flow and return, the individual siphons were hoisted by floating cranes into their final position.

Thanks to the high degree of prefabrication with superb quality standard, site assembly could be carried out rapidly, simply and inexpensively, thus guaranteeing safe operation of the pipeline for the future.

The background situation

A new combined heat and power station is being constructed to supply heat to Amsterdam Zuidoost. This station, which is to be completed in 1998, will have an electrical capacity of 250 MW and a heat capacity of 183 MW. The output of heat is to be further increased in a second stage of development at the power station.

For the distribution of the heat a high-temperature water pipeline is being constructed, which is designed to transport a heat capacity of 380 MW. This pipeline is being built to the parameters listed in *Table 1.*

The pipeline will be some 6.5 km long and is being constructed predominantly of plastic-cased pipe-in-pipe. However, the pipeline crosses three waterways, and for these crossings steel-cased pipe-in-pipe siphons have been used. The following report is concerned exclusively with the steel-cased pipe-in-pipe siphon that crosses a major waterway, the Amsterdam Rijnkanaal. This siphon is 135 metres long.

The maximum supply temperature will be 135 °C. The pipeline is being laid in organogenic foundation material, where settling differences of up to about 700 mm are to be expected. In order to take account of these exceptional forces, equally exceptional measures had to be taken during the laying of the plastic-cased pipeline. The construction of the three siphons involved stresses exceeding the limits for plastic-cased pipe-in-pipe systems; the siphons were therefore manufactured from steel-cased pipe-in-pipe, which when correctly designed is able to withstand even exceptional strains.

The route of the pipeline was chosen in such a way that the siphon would cross not only the Amsterdam Rijnkanaal waterway but also a railway line at the same time. This made the problems attendant upon the installation of the siphon even more difficult, as it had to be threaded through under a railway bridge. This peculiarity of the project will be explained in more detail in the section on installation.

The problem

Generally speaking, the inner pipes of district heating pipelines have to be designed to withstand stresses from internal pressure, heat expansion (temperature) and the dead weight of the pipeline itself. The encasing pipe of the steel-cased pipe-in-pipe system is subject to stresses from soil and traffic loads, from vacuum and from heat expansion (temperature). A siphon requires special measures in any case, in order to take up the strain of its own dead weight and to compensate for heat expansion in the vertical shanks. In addition, the settling differences that occur have to be taken into account.

Originally, the initial planning envisaged the pipeline being operated at an internal pressure of p_i = 23 bars in the prressure rating level PN 25; it was accordingly intended that the inner pipe should be made of material St 52.0 and that the straight pipe should have a wall thickness s = 10 mm. This meant that almost the entire strength of the material would be required to withstand the stresses from internal pressure alone, so that there would be only a small reserve margin to cope with the remaining sources of stress.

FW-FERNWÄRME-TECHNIK GmbH had already embarked upon the planning of the siphon when the operating parameter pressure was increased to p_i= 30 bars. Despite this, no increase in the wall thickness could be contemplated for reasons of costs.

The use of material St 52.4 with a guaranteed high temperature yield strength made it permissible to reduce the safety coefficient for primary stresses from S = 1.8 to S = 1.5. Calculations using simple boiler formulae are enough to show that merely after taking account of the internal pressure stresses the reserves of strength were now even smaller, despite the use of the higher grade of steel St 52.4, than in the original design. In practical terms, this meant that the compensation elements in the pipeline had to be made very yielding, so that the movement of the inner pipe within the encasing pipe would create as little stress as possible. This required specially designed bearings, which made great demands on the engineering.

In addition, special designs were necessary for all the pipe bearings. This was because they would be subjected to additional strain during the installation of the prefabricated siphon, as the stresses arising during installation would be exerted at an angle of 90° to those occurring during operation.

The special soil conditions in the Netherlands have the effect, as has already been mentioned, of producing additional loading on both the inner and the encasing pipe in the vertical shanks of the siphon. *Figure 1* shows the particular situation in which the steel-cased pipe-in-pipe siphon and the adjoining sections of plastic-cased pipe-in-pipe were to be installed.

The plastic-cased pipe-in-pipe is for the most part laid in organogenic soil. The steel-cased pipe-in-pipe siphons and in particular their vertical shanks are located in the dyke area of the Amsterdam Rijnkanaal, where the soil is extremely compacted. In the area where the plastic-cased and steel-cased pipes join, the plastic-cased pipe-in-pipe can be expected to be subject to settling differences of up to 700 mm. It was therefore decided to incorporate a series of 90° turns in the pipeline, so that the settling differences would be compensated for by torsion and the bending of the pipes. At the end anchors of the steel-cased pipe-in-pipe, where this is joined up to the plastic-cased pipe sections in the ground, substantial forces and moments occur, so that a special survey of these was necessary as well.

The rigid embedding of the steel-cased pipe-in-pipe in the dyke area makes particular demands on the design of the encasing pipe, since either an elastic, i.e. thin-walled or a rigid, i.e. thick-walled design would be conceivable. It was up to the engineers to decide upon the most suitable variant.

Technical solutions

In elaborating solutions to such problems, FW's engineers are able to draw upon both their many years of experience and their thorough engineering knowledge, which is supported by modern computer systems. It thus goes without saying that the firm is in a position to compute pipelines by the finite element method for three- dimensional frameworks. For computations which are required frequently FW has produced its own software, so that, for example, the statics of anchor designs can be demonstrated, or calculations can be carried out such as those to demonstrate the stresses produced on encasing pipes by earth and traffic loadings as per ATV worksheet A 127.

Compensation for the heat expansion of the inner pipe had to be effected by natural means, without prestressing. Problems arise from the dead weight of the vertical shanks, their heat expansion and the settling differences, and also from the interval of 6 metres between bearings, which is small for a pipe of DN 900 nominal diameter and might result in the inner pipe lifting off at individual bearings.

The very high stresses from internal pressure had to be compensated for by the design of a very soft bearing system. The dead weight, which because of the heat expansion of the vertical shank and the settling that was to be expected would exert forces extending beyond the vertical shank itself, had to be absorbed either by a very high capacity bearing on the vertical shank or else by a special type of suspension.Comparative calculations showed that the option of supporting the vertical shank on a very high capacity bearing in front of the bottom elbow caused the least amount of constraint. In determining the distribution of loads between the individual bearings, the deformation of the bearings also had to be taken into account.

Since the settling differences between the steel-cased and the plastic-cased pipe-in- pipe and also the forces of friction on the plastic-cased pipe-in-pipe are substantial, powerful forces and moments are exerted on the end anchors of the steel-cased pipe-in-pipe (F_{axial} up to 700 kN, M_b up to 1000 kNm) so that these had to be made torsionally elastic in order to minimise the moment stresses. In this way it was possible to achieve permissible levels of tension in the inner and encasing pipes and also in the anchor plates. Torsional elasticity was achieved by incorporating into the encasing pipe lenticular compensators equipped with devices to prevent excessive deformation.

The material selected for the encasing pipe in the lower area of the siphon was welded steel pipe DN 1100 with a wall thickness of s = 11 mm, made of material St 52.0 as per DIN 1626. In the dyke area, and in the organogenic soil as far as the junction with plastic-cased pipe-in-pipe, the substantially higher stresses on the encasing pipe made it necessary to select a wall thickness of s = 20 mm in material St 52.0, while the amount of space required for expansion necessitated a nominal diameter of DN 1200 *(Figure 1)*. The insulation has a thickness of s = 70 mm throughout.

Prefabrication of steel-cased pipe-in-pipe

The steel-cased pipe-in-pipe was prefabricated in FW's No. 2 Plant in Celle. The construction units are up to 12 metres long, and shaped pieces such as elbows, anchors etc. were mounted on to these units at the factory, in order to simplify assembly on site to the greatest possible degree.

This project was subject to supervision by the Dienst voor het Stoomwezen. The TÜV exercised this function at No. 2 Plant on behalf of the Dienst voor het Stoomwezen.

Figure 2 shows the manufacture of a construction unit incorporating an elbow.

After the inner pipe bend - a welded elbow as per DIN 2605, construction type 3 - had been welded on to the straight sections of pipe, the weld seams had to be submitted to 100% radiographic testing by our own laboratory. The X-ray films were afterwards scrutinised by an independent TÜV expert. The pipe bearings were then installed and the inner pipe enclosed in segmental shells of mineral wool affixed with bands of stainless steel. As can be seen in *Figure 2*, the bends in the encasing pipe are composed of closely-fitting segments. When the segments of the encasing pipe had been welded together the weld seams were wrapped in cold-worked anti-corrosion bandages as passive protection against corrosion. The prefabricated construction units were transported to the site by lorry. For purposes of documentation, the pipe log-book together with the report of the independent TÜV expert have to be submitted to the Dienst voor het Stoomwezen.

Assembly of the steel-cased pipe-in-pipe

The siphon was assembled on an assembly emplacement on the bank of a branch canal off the Amsterdam Rijnkanaal, as is shown in *Figure 3*.

In view of the high degree of prefabrication of the steel-cased pipe-in-pipe, all that had to be done on site was to join the sections together. The vertical shanks were supported on structures made out of containers. In the case of this on-site assembly too, the weld seams in the pipeline were submitted to 100% radiographic testing, and were also presented to the expert from the Dienst voor het Stoomwezen for examination. As the siphons were to be floated into place, the inner and encasing pipes had to have metal plates welded on to their ends to create watertight seals.

In *Figure 3* the completely assembled steel-cased pipe-in-pipe siphons of the district heating supply and return pipelines are visible, together with a gas supply siphon. The individual siphons were hoisted on to the surface of the water by three floating cranes and the vertical shanks rotated downwards through 90°, so that each siphon was floating freely on the water. The siphons were kept overnight floating on branches of the Amsterdam Rijnkanaal. Next day, they were towed separately by barges to the point where they were to be submerged. The three floating cranes were also positioned at the same place.

The siphons cross the Amsterdam Rijnkanaal by the shortest distance, and also pass under a railway bridge, which they had to be threaded through. *Figure 4* shows a floating siphon that has already been passed under the bridge and is being prepared to be hoisted upright again by the floating cranes, in order to be brought into its final position.

Figure 5 shows a siphon restored to the vertical, which is just being brought into position. The siphons were submerged in the following way: each siphon was first suspended at a gradient above the surface of the canal and the inner pipe slowly filled with treated water from a tanker ship until the siphon sank. The gradient was necessary in order to prevent the siphon from starting to rock uncontrollably as water flowed backwards and forwards in the inner pipe.

For filling purposes fire brigade hoses were attached to the inner pipe; these can be seen on the left-hand edge of *Figure 6*. When the inner pipe was full of water, a pressure trial was carried out at a test pressure of 41 bars.

Subsequently, the under-water pipe trench was refilled with sand. The assembly of the remaining steel-cased pipe-in-pipe construction units as far as the junction with the plastic-cased pipe-in-pipe was effected directly in the trench, which had to be kept well drained of water.

Construction moisture was removed from the heat insulation and the encasing pipe by dry evacuation of the system, in order to avoid corrosion and improve the heat insulation. In this case, the evacuation of the pipeline took place before the system was taken into operation. This is not to occur until a year after the pipeline has been completed.

In order to further enhance the protection against corrosion, the entire pipeline is equipped not only with passive protection but also with a cathodic anti-corrosion system.

Further prospects

Steel-cased pipe-in-pipe is especially suitable not only for the construction of district heating systems, but also for transporting liquids which represent a hazard to water. FW, as a specialist undertaking under Section 19 l of the Water Management Act, supplies and installs pipelines for water-endangering substances, including flammable liquids.

As special accessories to its steel-cased pipe-in-pipe systems, FW also supplies completely prefabricated steel chambers *(Figure 6)*. These serve for the underground installation of the necessary controls and fittings. The chambers are watertight, and consist of a cylinder of steel sheeting to which the floor and roof sheets are welded, with a flange acting as an earth anchor to counteract any tendency of the chamber to lift. These steel chambers are reinforced and will withstand the stresses caused by loads of bridge class SLW 60.

Table 1: Technical data of the Amsterdam Rijnkanaal siphon

Inner pipe:
DN 900 (914 mm x 10 mm), St 52.4,
DIN 1628, elbows DIN 2605, BA 3

Insulation:
70 mm, mineral wool shells

Encasing pipe:
DN 1100 (1,120 mm x 11 mm),
DN 1200 (1,220 mm x 20 mm),
St 52.0, DIN 1626

Design temperature, supply/return pipes:	135°C
Rated pressure level:	PN 40
Internal pressure:	30 bars
Length of siphon:	135 m

Figure 1: Overview drawing

Figure 2: Prefabrication of a steel-cased pipe-in-pipe construction unit with elbow

Figure 3: Finally assembled steel-cased pipe-in-pipe siphon with a gas supply siphon alongside

Figure 4: Floating steel-cased pipe-in-pipe siphon

Figure 5: Steel-cased pipe-in-pipe siphon being hoisted into position for submerging

Figure 6: Steel chamber