The Significance of Steel Pipe in the Rehabilitation of Pipelines and Distribution Systems

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SUMMARY: The fact that steel pipes have been used in gas and water distribution systems for more than a century has resulted in the emergence of two entirely different perspectives regarding the pipe rehabilitation planning. While, on the one hand, steel pipe is indeed used with great success in the rehabilitation of existing pipelines, older steel pipelines on the other has since outlived its use and is thus itself in need of rehabilitation. Circumstances dictate that any evaluations on old pipes for the purpose of planning rehabilitation projects will have to be based on statistical data if there is no measurement system in place to enable constant monitoring. This article presents a method of differentiating between the various technological states of development in steel piping. We will, in keeping with the second perspective, also examine examples of modern steel pipe construction in the trenchless rehabilitation of pipe networks.

1. INTRODUCTION

The role that steel pipe has to play in a pipe network is twofold when considering the issue of maintenance. The fact that steel pipes have been used for over a century in the supply of gas and water means not only that it is a suitable resource in the rehabilitation of pipe networks, but also that it will inevitably itself eventually require rehabilitation. Rehabilitation, together with repairs, constitutes a fundamental element of the restoration and thus also maintenance of a supply network. We distinguish between pipes or pipe networks with and without cathodic protection depending on the approach taken to maintenance [1].

The development of cathodic protection for steel piping in the 1950s provided us with a crucial tool for keeping pipes in good condition. Cathodic protection offers the opportunity to monitor pipes or pipe networks and to precisely establish the location of any defects. As cathodic protection is an anti-corrosive measure in its own right, it enables us to plan for the long-term rehabilitation of pipes if certain areas might become damaged. Software solutions such as WinKKS, which can be used as a planning tool for maintaining the condition of a pipe network, also provide assistance [2].

The use of cathodic protection and welded steel pipes has become a particularly well-accepted combination in systems for which security and safety are significant issues, such as in the transport of substances that pose a risk to groundwater or are inflammable, but also in the transport of water and sewage. These advantages are most notably applied in the welded steel piplines used to distribute gas throughout our towns and cities. Being able to record and evaluate measurements regarding the state of a pipe network from the surface not only provides the means to determine how carefully a network has been laid, but also allows us to constantly monitor it while it is in operation. External influences along the length of the pipeline can be recorded in this way and any resulting damage can be repaired. The high level of usage that a pipeline can sustain in this way contributes considerably to reducing the operating costs of a pipe network. The ability to evaluate pipelines to aid in the planning of rehabilitation projects is of particular significance today. The ability to locate defects and damage allows projects such as these to be solely restricted to parts of a pipeline that really are in need of rehabilitation [3].

The first documents in Germany published to provide assistance in the planning of rehabilitation measures for pipelines in the gas and water industries, DVGW advisory W 401 and DVGW worksheet G 401, provided a general overview of the most fundamental aspects of a more preventative form of maintenance [4], [5]. Cathodic protection played only a minor role in these initial publications. These two regulatory documents are currently being replaced by DVGW worksheet W 402 and advisory W 403, and by worksheets G 402 and G 403 for water and gas respectively [6], [7], [8], [9]. The collection of data regarding damage to and the condition of pipe networks and information on maintenance strategies is covered in each of the relevant regulatory documents, with information provided by measurements taken on cathodic protection also being taken into consideration. While data from the measurements of cathodic protection is fed directly into the planning of repair or development projects, all forms of pipe networks or pipelines without cathodic protection must be evaluated on the basis of statistics with regard to the pipe design and expected service life. When evaluating damage as part of the standards laid out in these worksheets, both the cause of damage and the relevant information regarding condition must be recorded. This is the only way that the resulting service life can also be attributed to a specific pipe design.

The pipe design affected by damage can be determined from either the existing operating documentation or from the in situ analysis. The new factor is the requirement to differentiate between different types of corrosion damage with regard to the actual cause of the damage when handling pipes made of ferrous materials. Whereas any statistics regarding long-term usage were rendered useless in the past by "corrosion" simply being ticked as the assumed cause of damage, it is now necessary to enquire as to just how the corrosion damage actually came about. The reason for this is the fact that corrosion damage can have many different causes. For example, steel pipes usually had thick coatings applied in the last decades. Any corrosion developing in these cases was generally the result of damage or a lack of care in laying. However, these are causes that say nothing about the service life in relation to the design, and thus are also of little relevance to statistical records examining service life. **Table 1** provides an overview of the damage categories that must be recorded in future and their significance in the planning of rehabilitation. A glance at the table also

Damage category	Consequence for planning
External mechanical and thermal influences	Usually localised damages - repair
Seismic activity	Usually localised damages – repair Sections of network - affects areas with pronounced subsidence.
Corrosion and deterioration of materials (excluding other categories, usually limited to designs with absent or poor anti-corrosion protection)	Sections of network - affects areas with same pipe design, laid during same period of time and under same fundamental conditions (ground, stresses,...)
Errors in laying and fitting	Sections of network - sections affected by systematic errors in laying are those that form part of the same laying project.
Material defects	Sections of network - with manufacturing defects, pipes or pipe designs from a specific manufacturer are affected.

TABLE 1: **Overview of the damage categories to be evaluated and the consequences for rehabilitation planning**

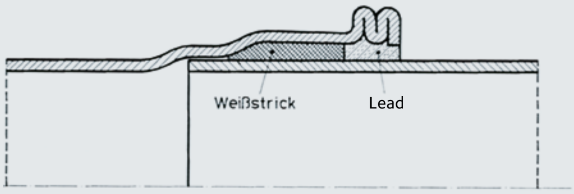

FIG. 1: **Long-seam welded pipe with caulked lead joint and double flare as reinforcement**

FIG. 2: **"Safety rubber ring sleeve" coupling**

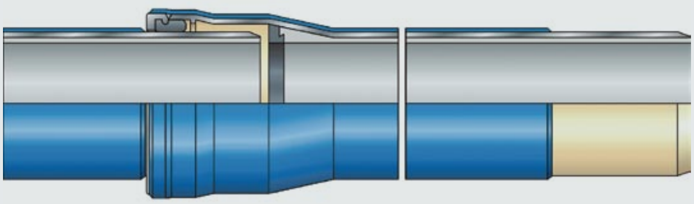

FIG. 3: **Tyton® spigot-and-socket joint**

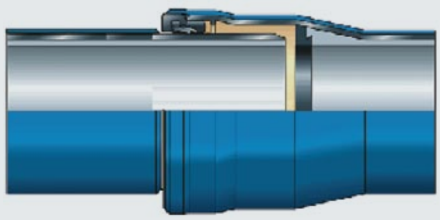

FIG. 4: **Tyton-Sit® spigot-and-socket joint**

reveals that each damage category generally reveals the possible cause of the corrosion damage. If no categorisation is carried out during the recording of corrosion damage, it will not be possible to separate damage arising from external influences from damage resulting from deterioration. As an example, the previous regulatory documents provided service life statistics in the appendices, which were intended to provide an initial overview of the expected timeframes. Concealed within these statistics were estimates for situations where real data was impossible to obtain, particularly with more recent pipe designs. It is also noticeable that these statistics cover periods of up to 60 years for the expected service life. This large timeframe arises from a number of factors related to specific networks, such as:

- » the care taken in laying
- » ground conditions
- » transport stresses
- » activities around the pipeline
  etc.

A lack of care in the record-keeping for the pipe networks makes deciding for or against renewing the pipelines or restoring/repairing existing ones extremely difficult based on statistics such as these. The material-specific service life time periods specified in the appendices of the worksheets are by no means sufficient to act strategically in the planning of pipe renewals. [10]. Disadvantages here might be that sections of pipeline that are still fully intact would be replaced, or that too much time is allowed to lapse before replacing or restoring pipes, thus resulting in not only the primary costs for the repairs, but also the secondary costs for remedying subsequent damage. The system of data collection required today allows for a considerably more precise evaluation of the situation in the pipe networks. Aside from factors specific to a particular network, the steel pipe designs, which are categorised according to their time of manufacture, are also of critical significance in the generation of service life statistics and thus for the evaluation of a steel pipe network. The sections hereafter provide an overview of the various steel pipe designs used in the past and the present and provide a rough framework for carrying out network analyses such as these. A further section will introduce the possibilities of using steel pipes in the rehabilitation of a pipe network using selected examples.

2. THE TECHNICAL DEVELOPMENT OF THE STEEL PIPE

2.1 The production of steel pipes

The story of the steel pipe as it is used in the gas and water supply industries begins at the end of the 19th century. Seamless or welded steel pipes were used during this period, depending on the field in which it was to be used. While welded steel piping was primarily used for the ventilation and drainage of mines, the supply of water and the disposal of sewage, only the gas and oil industries, for whom safety and security were of more concern, made use of seamless steel pipes until the 1960s. It was only once welding techniques were refined and optimised that the seamless steel pipe was superseded. One of the milestones in the development of steel pipe technology was the first patent for the manufacture of seamless steel pipes issued to the Mannesmann Brothers in 1886. The first records of welded steel pipe being manufactured date back to 1845 in the town of Mauel, in the Eifel district of Germany. The edges of a steel strip material was heated to welding temperature and welded by pressing the edges of the bands together. The first steel pipes manufactured using arc welding were produced in the 1920s. Here, the band edges of the strip metal bent towards the pipe were welded by hand or by machine with the help of additional material. Even today, pipes with large diameters continue to be manufactured using a submerged arc welding processes making use of additional material. Powder is used during the welding process to prevent the electric arc being exposed to oxygen (material by wire electrodes).

Induction welding, which involves the use of a ring inductor to induce the welding current into the endless steel strip bent towards the pipe, was used for the first time to manufacture steel pipes in the 1950s. The current heats the band's edges, which are pressed together at the weld spot. The compression process allows band edges to be welded together without using additional materials. A scraper is used to work off the material developing on the inside and outside during the compression process so as to achieve the desired pipe wall thickness. This type of welding is limited to a nominal size of up to DN 600. It was only with the help of induction welding and submerged arc welding that it was possible to also weld high-strength pipe materials together.

2.2 Joint techniques

When considering techniques used to join steel piping, we distinguish between mechanical joints and weld joints. The caulked lead joint was the main pipe connection used at construction sites until well into the 1930s. A wide variety of types were used. On seamless pipes, the pilger head that develops at the end was used to create the reinforced sleeve. On welded pipes, the previously broadened pipe end was reinforced with a double flare or with an additional specially-adapted ring (**Figure 1**). The relatively low permissible axial movements meant that the so-called "Schalker" sleeves were used in areas of mine subsidence. With this joint, the spigot end is inserted into a longer guide section of the socket, enabling it to absorb any considerable axial movements. A cupped caulked lead joint, which allows for bending by up to 8°, was also common.

The fitting of the caulked lead joint required a relatively large amount of effort. First, a sealing rope had to be caulked into the cone-shaped sleeve using a yarning tool and lump hammer. The finish comprised either lead wool mortised in or the the remainder of the sleeve opening being filled with liquid lead. Led joint sockets were used both in gas and water supply systems. As former West Germany urban or long-distance gas supplies switched to natural gas around 1970, the sealing ropes dried out and many began to leak. Repeated attempts were made to counteract this effect using swelling agents.

In addition to lead sockets, rubber-sealed socket joints were also common back in the 1930s for water pipes. The so-called safety rubber ring sleeve (German: Sigurmuffe or Sicherheits-Gummi-Ringmuffe) involved the placing of an O-ring gasket on the spigot end (**Fig-**

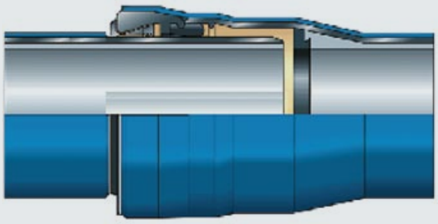

FIG. 5: **Double chamber socket (DKM®) spigot-and-socket joint**

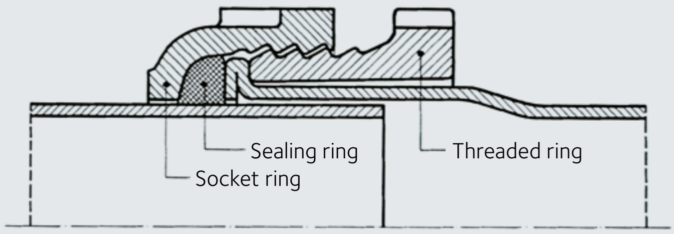

FIG. 6: **Threaded joint DN 40 to DN 250**

FIG. 7: **Welding Socket joint**

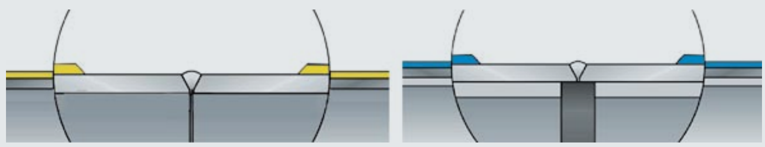

FIG. 8: **Pipe end finish for butt weld joints in gas and water pipelines**

FIG. 9: **Submerging steel piping in a bitumen bath**

FIG. 10: **Spin head used to coat the pipes**

ure 2) Once prepared in this way, the spigot end could then be inserted into the trumpet-shaped widened pipe end. This kind of mechanical joint had already become irrelevant in the 1970s, however. At the beginning of the 1980s, the steel spigot-and-socket joint system with the Tyton® ring known from cast iron piping was introduced. The standard design established by the German standard DIN 2460 allows the steel spigot-and-socket joint to be used for service pressures up to 40 bar [11] (**Figure 3**). Tyton-Sit® and double chamber socket (DKM®) joints are available as longitudinally force-locking systems. These joint types can be used in their standard forms to withstand longitudinal forces under an operating pressure of up to 40 bar (**Figure 4 and 5**). Longitudinally force-locked spigot-and-socket systems such as these continue to be used today in the trenchless laying of pipelines or renewal of pipes.

Alongside sleeve joints, screw joints were also used in the 1950s for smaller nominal sizes of up to DN 500. Two designs for nominal sizes from DN 40 to DN 150 and from DN 200 to DN 500 were distinguishable here. With smaller nominal size ranges, the threaded sleeve was fitted by inserting the copped end into the wider part of the next pipe section. This widened piping was double flared so as to provide support for the rubber ring required to seal the pipe (**Figure 6**). During fitting, a sleeve ring placed on the narrow end was joined with the threaded ring located around the sleeve behind the double flare.

When using threaded joints with larger nominal pipe sizes, the double flaring is omitted. During fitting, a tapered rubber ring would be pressed into a widened pipe end with the help of a threaded ring. A steel spiral is welded into the sleeve as a thread. A slide ring between the rubber gasket and threaded ring prevented the rubber from being stripped during fitting. The weld joints have been used as an alternative to the caulked lead joint since around the 1920s. Socket structures were initially used to this end, to relieve a considerable amount of the stress on the weld seam. **Figure 7** shows the usual socket welding design that is still used in the sewage industry today.

Butt welded joints were still considered a safety risk at that time. As explained in the Mannesmann Röhrenwerke manual from 1936: [12]:

"The simplest weld joint is the butt weld. Here the pipes are, if necessary, calibrated at the ends and tapered to an angle suitable for welding. In spite of its great strength, this simple butt weld does not provide the required safety in many applications. For this reason, more suitable joints have been developed for such purposes."

The following can be found in the manual from Phönix Rheinstahl dated 1956 [13]:

"Butt welding is a simple joint used for pipes with smooth ends and is technically speaking not a sleeve joint. Proper implementation requires the pipe ends to be well centred; this is thus particularly well-suited to pipes of a good firmness, which prevents the pipes from losing their roundness. ... The joint is very simple. If welded properly, it possesses excellent strength almost comparable to that of the full cross section of the pipe itself. Longitudinal forces can thus be absorbed by the joint to a large extent." In a study by the DVGW regarding the various joints used in underground drinking water pipelines, the butt weld joint was described in 1978 as follows [14]:

"The use of this joint is preferred for all diameters and wall thicknesses and for both round and segment seams. Butt welds represent the ideal joint in welding. They are relatively easy to create, easy to check and transmit forces with no bending stress." With improvements in welding

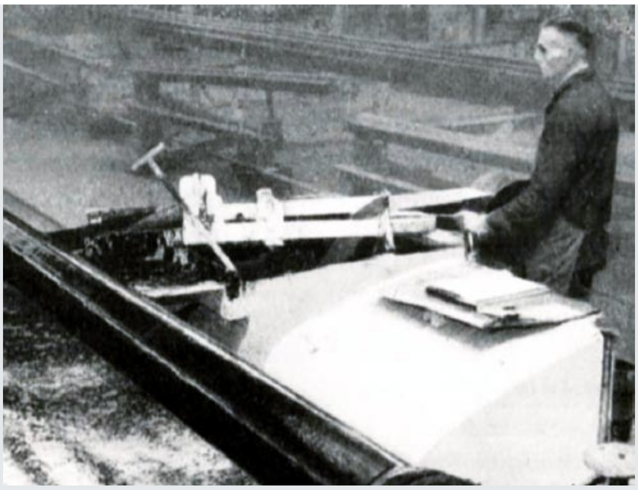

FIG. 11: **Wrapping the pipes with woven soaked in bitumen**

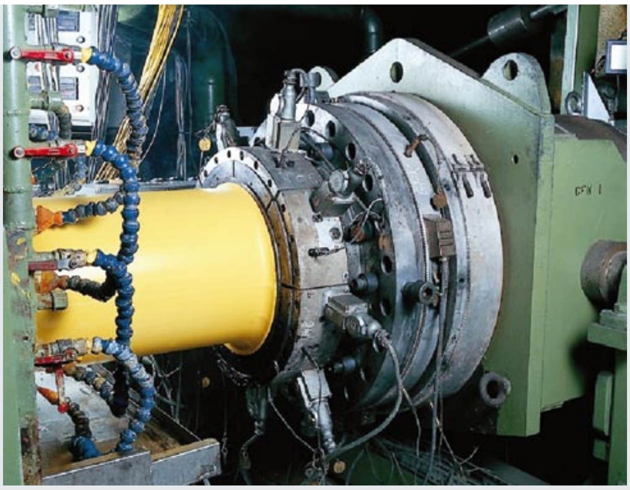

FIG. 12: **The sleeve extrusion process**

technology, optimised welding procedures and stricter tolerances with steel pipes, butt weld seams are the preferred solution in pipe fitting and are currently the best available technique in gas and water supply systems. (**Figure 8**).

2.3 Corrosion protection

2.3.1 Lining

While gas pipelines require no interior anti-corrosive applications, water pipelines made of steel require an anti-corrosive lining. Bitumen lining is perhaps the oldest form of interior anti-corrosion protection used in Germany for steel water pipelines. The lining thickness is related to the corrosiveness of the medium to be transported. The pipes are usually either dipped or coated inside with a thin coat of bitumen (**Figure 9**). This form of corrosion protection was selected for types of water that permit the development of passive surface layers. For more corrosive water types, a rolling process was used to build up dense coatings of blown bitumen with thicknesses of up to 2 mm. For particularly corrosive fluids, it was possible to further thicken the lining to 4 mm by using a special type of bitumen. These coatings have gradually been superseded since the mid-1960s by cement mortar lining. Cement mortar linings are far superior to organic linings, both in terms of their economic and their anti-corrosive properties for the drinking water and sewage industries. Requirements related to cement mortar linings today are defined in the European standard DIN EN 10298 [15].

The use of cement mortar as an anti-corrosive agent in water pipelines made of ferrous substances was first described in a publication from the French Academy of Sciences dated 1836 [16]. Among the various procedures considered for the protection of the interiors of pipelines, a particularly cost-effective solution was presented in the form of a cement mortar lining of at least 2.5 mm thickness, guaranteeing good handling as well as protection against corrosion and thus incrustations. It is not unreasonable to assume that this publication was the reason why cement mortar linings began to be used in the United States just a few years later. It was documented as early as 1845 that pipes coated in cement mortar were laid in Jersey City, New Jersey. The regulations of the City of Brooklyn of the State of New York dated 1859 mention cement mortar linings.

Early procedures for lining pipes presented some extraordinary problems nonetheless. For example, a so-called "drawing" process was developed to enable cement mortar linings to be applied with the help of a mandrel. The cement mortar lining thicknesses were subject to considerable variations due to poor centring. The spin lining method still common today was developed around the 1920s. Here, once the cement mortar has been applied to the pipe, it is spun around to achieve a smooth and evenly thick coating. Generally speaking, there are two methods of pipe lining that we can distinguish between:

The rotational spinning method involves the introduction of an aqueous mortar into the pipe before it is spun to spread, seal and smooth it across the circumference of the pipe. Excess water is expelled during this process. Cement mortar linings applied according to this procedure are characterised by a clear layer of fine particles, which primarily consist of cement. With the spraying method, the first step involves the introduction of the mortar to the inside of the pipe. The pipe is then spun to even out and compact the mortar. Depending on the spin speed and amount of water expelled, it is possible to produce linings with a homogenous particle size distribution (**Figure 10**).

2.3.2 Coatings

As with linings, bitumen was also initially used for coating steel pipes. The first step towards coating a steel pipe was to apply a primer layer, generally by dipping the pipe in a bitumen bath. It was then wrapped with woven soaked in bitumen to the desired coat thickness (**Figure 11**). Until the 1950s, woven of jute waterproofed Cardboard material was used to be soaked in bitumen and wrapped round the pipes. Glass woven were used as an alternative later. In contrast to cardboard or jute, glass woven were considerably more resilient. It also lacked the wicking effect with moisture that organic materials exhibited. The now-coated steel pipe was then whitewashed or sprinkled with talcum powder to protect it against sunlight.

The first polyethylene coatings were produced towards the end of the 1950s using the so-called sintering technique [17]. The pipes were first blasted with steel granulate to reveal the bare metal. At a surface temperature of around 300°C, polyethylene powder would trickle down onto the rotating pipe, which melted upon contact with the pipe surface to form an even layer. These powder coatings had the disadvantage, when compared to the later produced extruded coatings, of being less adhesive and more prone to breaking due to poor elasticity. Sintered polyethylene is relatively brittle when compared to the extruded materials usually used today.

The sleeve and side extrusion processes in common use today have been used since the mid 1960s and have since completely superseded the sintering technique with regard to pipe coating. Initially, a two-layer coating was produced consisting of adhesive and polyethylene. High-quality three-layer systems began to be used in the mid 1980s. These three-layer coatings also have an additional epoxy resin based primer. These systems, which have been developed with practical considerations in mind, achieve a higher adhesive strength and allow the polyethylene to be cut back easily by heating the pipe ends when cutting pipe sections. Low-Density, Medium-Density and High-Density Polyethylene (LDPE, MDPE and HDPE) are used. HDPE for example is applied for higher service temperatures. Compared to polyethylene, coatings of polypropylene are of little significance in the industry and are used primarily for special applications such as trenchless pipe-laying.

The fields of application of the sleeve and side extrusion techniques are generally limited to a number of specific steel pipe dimension ranges. The side extrusion technique is primarily used with larger pipes. After blasting the pipe to a surface preparation grade of Sa 2 1/2 and preheating the pipes to around 200°C, the epoxy resin primer coating is applied as a powder, before adhesive and polyethylene or polypropylene are applied via a side extruder using a pressure roller. When using sleeve extrusion, the primer and adhesive are usually applied as a powder

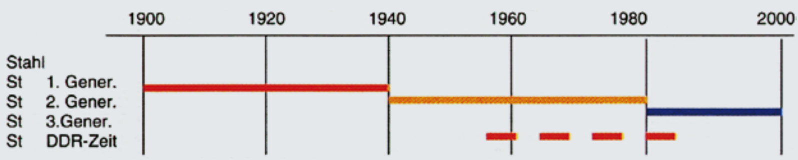

FIG. 14: **Generations of steel pipe according to Roscher [21]**

MAPEC© with T-section ribbing and FZM-S

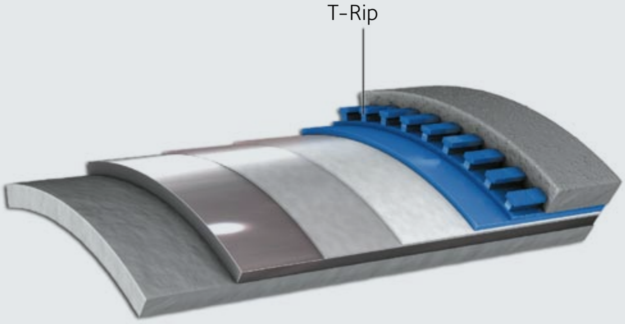

FIG. 13: **Cement mortar coating as used in the special design for trenchless pipe laying**

FIG. 15: **Laying a spigot-and-socket pipeline using the pipe drawing technique**

coating. The last step involves the extrusion of polyethylene or polypropylene as a seamless sleeve (**Figure 12**). Sleeve extrusion has managed to establish itself primarily in the treating of pipes of nominal sizes up to DN 600. The use of appropriate extruder attachments also allows profiled coatings to be produced. The requirements for polyethylene and polypropylene coatings have been established for example in the German standards DIN 30670 and DIN 30678 respectively [18], [19].

2.3.3 Cement mortar coating for mechanical protection

Steel pipes with polyethylene or polypropylene coatings must be embedded in stone-free material in accordance with the technical regulations. The savings possible with the use of beddings such as these was the trigger for the development of a cement mortar coatings used to protect the polyethylene coating from mechanical damage. Cement mortar coating has advantages from a technical standpoint, particularly the mechanical protection provided during laying and for the event that any digging activities around the pipeline might be necessary at a later point in time. The disadvantages of a sandbed, such as a wider working strip for the transport of sand and excavation material as well as the feared drainage effect in natural reserves and agricultural areas, no longer apply. The economic benefits are derived not only from the lack of a sandbed, but also from the fact that transport costs for sand, excavation and possibly landfill costs arising from the soil exchange no longer apply.

The preferred production technique for cement mortar coating today is comparable with the side extrusion process used for polyethylene coatings. The mortar, modified with plastic fibres, is applied to the rotating pipe via a flat-film extrusion die. To ensure that the fresh layer of mortar on the plastic-coated pipe surface is firm, a polyethylene woven wrapped around at the same time. The woven is worked into the surface of the mortar gently and, once set, effectively reinforces the mortar. The cement mortar coating of the steel pipe is produced in accordance with the German DVGW worksheet GW 340. This worksheet describes two designs (FZM-N and FZM-S) [20]. Design N is used in conventional pipe laying, whereas design S is used mainly in trenchless pipe-laying (Figure 13). As opposed to the FCM coating used in the normal design, the design intended for trenchless pipe laying contains a mechanical connection between the plastic coating and FCM coating. A T-profile is applied as a second layer between coating and the cement mortar layer (**Figure 13**).

2.4. A general summary of the generations of steel pipes [21]

It is absolutely necessary to take various generations of steel pipe into consideration when evaluating a pipeline network, a step which is necessary for the creation a maintenance plan geared towards prevention. In view of the multiplicity of developments and experiences in the application of steel pipes, assigning them to sections of a useful and relatively uncomplicated table is difficult. The quality of the anti-corrosion agent used contributes considerably to determining the service life of a pipeline made of ferrous materials. For this reason, a grid of this type should focus on the development of the anti-corrosion agent when determining the various generations of steel pipe (**Figure 14**). Pipes made of ferrous materials were already being coated and lined to protect them against corrosion back in the 19th century. This did not necessarily mean, however, that all pipes laid back then were sufficiently protected against corrosion to meet the needs of the intended application based on what we know today. This required knowledge that was yet to be discovered within the field of underground pipelines. It was on-

DN	d_a [mm]	Wall thickness [mm]	Permissible tensile force [kN]	Bend angle/ max. curve radius [°]/[m]
80	97	3.6	30	3/115
100	117.5	3.6	50	3/115
125	143.0	4.0	70	3/115
150	168.1	4.0	100	3/115
200	219.1	4.5	170	3/115
250	273.0	5.0	260	3/115
300	323.9	6.3	370	3/115

TABLE 2: **Permissible tensile forces, bend radii and bend angles of spigot-and-socket pipes with double chamber socket joint (pipe length 6 m)**

DN	d_a [mm]	Wall thickness [mm]	Permissible tensile force [kN]	Bend angle/ max. curve radius [°]/[m]
80	97	3.6	20	3/115
100	117.5	3.6	29	3/115
125	143.0	4.0	43	3/115
150	168.1	4.0	60	3/115
200	219.1	4.5	102	3/115
250	273.0	5.0	107	3/115
300	323.9	6.3	152	3/115

TABLE 3: **Permissible tensile forces, bend radii and bend angles of spigot-and-socket pipes with Tylon Sit® joint**

ly in the 1930s that underground pipelines were protected against corrosion using bitumen coatings as a matter of course and that bitumen linings were used specifically in the fields of water and sewage transport, Steel pipes used up until 1940 thus represent the first generation of steel pipes, which were often insufficiently or even sometimes not at all protected against corrosion.

Advances in the production of welded steel pipes, the developments of the first sintered polyethylene coatings and the introduction of cement mortar lining represent significant stages of development in steel pipes used for transporting gas and water, especially in the 1960s. The acceptance of developments such as these, however, was slow. Taking contemporary developments and improvements in the field of corrosion protection into consideration, it was clear that the significance and understanding of this topic had grown. Bitumen coatings, which were still used in the majority of cases, had improved considerably in this time thanks to the switch from woven jute and Cardboard to the more resilient glass woven. This renders the period between 1940 and 1980 the second generation of steel pipes.

From around 1980 onwards, high-quality polyethylene coatings had fully established themselves as a method of preventing corrosion in underground pipeline construction. Cement mortar lining was used as standard in steel pipes used to transport water and sewage. The period following 1980 is thus the third and current generation of steel pipes as used in the supply of gas and water. Steel pipes laid in the eastern part of Germany prior to the fall of the Berlin wall is to be classed as first or second generation due to the in part insufficient corrosion protection.

3. STEEL PIPES FOR THE REHABILITATION OF PIPELINES

3.1 Steel pipe designs

When rehabilitating old pipes, the incorporation of new steel pipes in existing pipelines has been common, as the laying of new pipes using conventional techniques and technology. The advantages of trenchless pipe laying also apply to these techniques, such as:

- low damage to the underground due to avoidance of subsidence
- rapid pipe laying, as there the time needed to repair the surface is reduced.
- residents and road users around the construction area are not hindered. Obstructions are kept to a minimum due to the smaller size of the pits. There is little noise from construction because the use of construction ve-

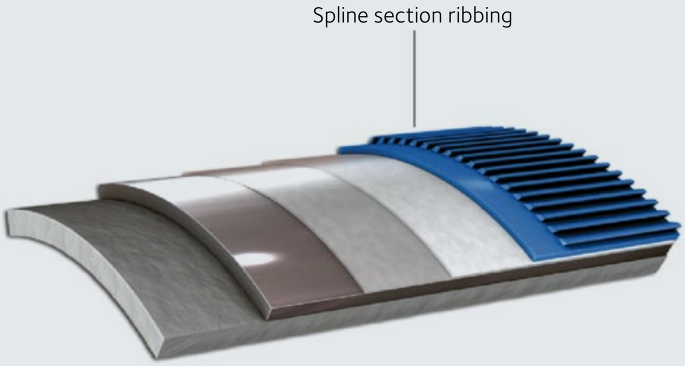

FIG. 16: **Profiled version of polyethylene coating**

FIG. 17: **Principle of the "Hydros" technique**

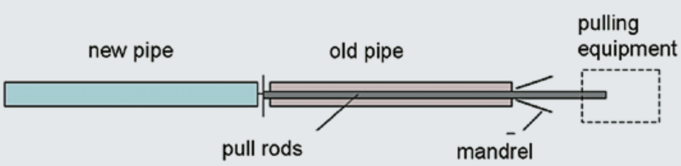

FIG. 18: **Starting pit for laying a pipe using the Hydros technique**

hicles can be avoided and the usual construction site activities associated with conventional pipe laying are no longer necessary.
- short construction times

For steel pipes to be laid using trenchless pipe laying techniques, the tensile forces and bend radii established in regulatory documents such as the German DVGW worksheet GW 321 apply [22], [23].

Depending on the design the maximum tensile forces and bend radii specified in **Tables 2 and 3** must also be observed with spigot-and-socket pipes [16].

The following options are available with regard to the rehabilitation of pipelines using steel piping:
- Laying of the new pipe inside an existing one - an "in-line" steel pipe
- Replacement of an existing pipe, for example by destroying the old pipe and laying the new pipe (e.g. using pipe bursting) or replacing the old pipe with a new one (e.g. using the "Hydros" technique)

As the laying route with these techniques makes use of an existing pipeline, dangers from pipelines belonging to other providers are usually not to be expected in spite of the generally high density of pipelines present under the streets. House connections must be located and disconnected beforehand. The most common techniques used for the rehabilitation of existing pipelines using steel pipes will be explained in a number of practical examples. It should be noted here, however, that there are many different accepted forms of steel pipe designs that are used depending on the technique in question.

3.2 Laying techniques

3.2.1 Steel pipe as inliner [24], [25]

When considering the inliner technique, we generally need to distinguish between structurally stable and unstable systems as used in tube relining. In terms of concept, the steel pipe is one of the structurally stable systems and is often used under conditions where the old pipeline can no longer meet these requirements. The laying of the new pipes in an existing pipeline will inevitably require the pipeline dimensions to be reduced.

Contrary to many previous expectations, water consumption has dropped over the past few years. There has been a downward trend in water consumption per household as well in the needs of industry over the past few years. For this reason, it may be worth considering a reduction in the size of the cross-section of older pipelines that are to be rehabilitated. The option of laying new pipes in existing pipelines seems practically destined for cases like these. One example here would be the pipe-laying technique used by "Gelsenwasser" since the early 1990s [17]. Both welded pipe joints and longitudinally force-locked spigot-and-socket joints are suitable for this inliner technique. The required pipe dimensions play a fundamental role when selecting the joining technique to be used. Mechanical joints will inevitably require more space than a welded pipe joint. The pits are arranged depending on the circumstances around the pipeline. It must be taken into consideration that bends, for example, cannot be passed through. In areas of mine subsidence, pipes must first and foremost be checked for any warping that may have arisen over the course of its service life as a result of soil movements. Inspection cameras also allow previously unknown fixtures to be located that may, under certain circumstances, prevent the laying of the new pipes.

The existing pipe is cleaned with scrapers and rubber pads before laying the new length. The laying of the pipes requires the drawing and fitting in the starting pit to be well-coordinated. The length is assembled pipe-by-pipe in the starting pit. With spigot-and-socket pipes, the area around the joint is protected from damage by an additional metal sleeve (**Figure 15**). Depending on the joints used, pipe lengths of up to 400 m may be laid. In the case of spigot-and-socket pipes, the pipeline is laid on the sheet metal sleeving around the joints during the laying process. In this case, there are no special requirements regarding the coating of the steel pipes. With butt-welded pipe designs, the pipeline load is spread out over the entire surface. Profiled polyethylene coatings are used particularly often in these cases (**Figure 16**). Once laid, the remaining hollow space between the old pipe and the new pipeline is usually filled with a cement based material.

3.2.2 Replacing existing pipelines

It is not feasible in all cases to reduce the cross-sectional size of an existing pipe for rehabilitation purposes. In trenchless laying, this means either destroying or removing the existing pipe. Replacing existing pipes generally requires the use of structurally stable pipe systems in contrast to inliners. Here it is also necessary to check the existing lines to see whether they are connected to houses or have other fittings. Issues such as these must be must be remedied beforehand to prevent problems.

Pipe bursting [26]

The pipe bursting technique is characterised by the wreckage or remains of the old pipe that it leaves behind. The new pipe is drawn in by destroying the old pipe in its place. It allows pipes with the same diameter or even with larger diameters to be drawn in. In these cases, the soil must be suppressed using an expanding head while the old pipe has been destroyed. Tools suitable for use with all pipe materials can be used to break up the old pipe.

For example, a 405 m length gas pressure pipe made of steel measuring DN 100 was replaced with a new with polyethylene and cement mortar coated steel pipe in two sections in June 2000 in Oberhaeslich, Saxony for Dresden-based Gaso. Two lengths of side welded steel pipes measuring approx. 200 m in length were prepared. The old steel pipe already in place was cut up, widened and the prepared lines drawn in. The old pipe was fitted in four steps. Once cut, the old pipe was widened twice. Upon widening the pipe a third time, the new steel pipe was drawn in simultaneously. The need to widen so often was primarily due to the resilient nature of the cut steel pipe. The presence of the cut old pipe means that the requirements regarding the mechanical stability of the coating systems used are stricter. The use of the special cement mortar lining technique has been well established in this case. In contrast to the lining technique, welding pipe joints are preferred.

The "Hydros" technique [27]

The "Hydros" technique (a.k.a. the hydraulic pipe drawing and split technique) has been used specifically in Berlin for more than ten years now. The aim of this technique is to replace usually old cast iron pipes with new ones without digging trenches. In contrast to pipe bursting, there are no remains or wreckage left in the ground. Both welded and longitudinally force-locked spigot-and-socket joints have proven their worth in the application of this technique.

The technique involves the drawing device in the target pit being introduced in such a way that it draws the old and new pipes in at the same time, allowing a mandrel to be used to destroy the old pipe in the process (**Figure 17**). This is achieved by feeding the pull rods through the old pipe and connecting to the end of the old pipe in the starting pit. The new pipe is hooked onto the pull rods. The pipe length to be laid is fitted in the starting pit (**Figure 18**). This means that the drawing and fitting stages must be coordinated during the laying process. The drawing of the old pipe is usually restricted to shorter routes and depends fundamentally on the strength of the material from which the old pipe is made. Thus, over a total drawing length of 60 to 80 m, there are usually several smaller pits, each of which is used to destroy partial lengths of the old pipe. Welded pipe joints and cement mortar coated pipes are also mainly preferred with this technique.

4. CONCLUDING REMARKS

The pipelines of a supply company represent around 60 to 80 % of their assets. Based on analyses now available, we

LITERATURE

[1] Kocks, H.-J.: Operation and maintenance of steel pipelines; 3R international 43 (2004) Special 13, p. 91 – 95

[2] Kocks, H.-J.; Voss, W.: „The pipe – the basis for a computer aided pipeline management"; 3R international Special Edition 2 (2010), p. 77-83

[3] Gaugler, H.; Kocks, H.-J.: Sense and nonsense of services-life statistic - Condition based maintenance of cathodically protected steel pipelines; 3R international 48 (2010) Special Edition 1, p. 53 – 58

[4] DVGW-Hinweis W 401 „Entscheidungshilfen für die Rehabilitation von Wasserrohrnetzen" (1997-09)

[5] DVGW-Arbeitsblatt G 401 „Entscheidungshilfen für die Rehabilitation von Gasverteilungsnetzen" (1999-09)

[6] DVGW-Arbeitsblatt W 402 „Netz- und Schadenstatistik – Erfassung und Auswertung von Daten zur Instandhaltung von Wasserrohrnetzen" (to be published)

[7] DVGW-Hinweis W 403 „Entscheidungshilfen für die Rehabilitation von Wasserrohrnetzen" (to be published)

[8] DVGW-Arbeitsblatt G 402 „Netz- und Schadenstatistik – Erfassung und Auswertung von Daten zum Aufbau von Instandhaltungsstrategien für Gasverteilungsnetze" (to be published)

[9] DVGW-Arbeitsblatt G 403 „Entscheidungshilfen für die Rehabilitation von Gasverteilungsnetzen" (to be published)

[10] Hofer, P.: 3R international, 33 (1994) p. 19-25

[11] DIN 2460, Stahlrohre für Wasserleitungen, January 1992

[12] Das Rohr im Dienst von Gas und Wasser, Handbuch der Mannesmannröhren-Werke Düsseldorf, 1938, p. 64

[13] Stahlmuffenrohre, Handbuch der Phoenix-Rheinrohr, Düsseldorf 1956, p. 54

[14] Studie über erdverlegte Trinkwasserleitungen aus verschiedenen Werkstoffen. Bericht III Rohrverbindungen, DVGW (Eschborn) Bonn 1978

[15] DIN EN 10298 "Steel tubes and fittings for on shore and offshore pipelines – Internal lining with cement mortar" (2005-12)

[16] Kocks, H.-J., Siedlarek, W.: Zementmörtelauskleidungen für Trinkwasserleitungen aus Guss und Stahl; Werkstoffe und Korrosion 53 (2002) 8, p. 546 – 559

[17] Kocks, H.-J.: Umhüllungen und Ummantelungen von Stahlleitungsrohren; 3R international 40 (2001) No. 1, p. 61 – 64

[18] DIN 30670 „Umhüllung von Stahlrohren und -formstücken mit Polyethylen" (1991-04)

[19] DIN 30678 „Umhüllung von Stahlrohren mit Polypropylen" (1992-10)

[20] DVGW-Arbeitsblatt GW 340 „FZM-Ummantelung zum mechanischen Schutz von Stahlrohren und -formstücken mit Polyolefinumhüllung" (1999-04)

[21] Roscher, H.: Sanierung städtischer Wasserversorgungsnetze; Verlag Bauwesen, Berlin, 2000, p. 46 – 49

[22] DVGW-Arbeitsblatt GW 321 „Steuerbare horizontale Spülbohrverfahren für Gas- und Wasserrohrleitungen" (2003-10)

[23] Kocks, H.-J.: The steel pipe in trenchless technology; 3R international 47 (2008) Special Edition 1 p. 72 – 79

[24] GW 320-1 „Erneuerung von Gas- und Wasserrohrleitungen durch Rohreinzug oder Rohreinschub mit Ringraum" (2009-02)

[25] Kleinau, A.: Leitungserneuerung durch Rohreinzug von duktilen Gusseisen- und Stahlrohren; bbr 51 (2000) 9, p. 23 – 27

[26] GW 323 „Grabenlose Erneuerung von Gas- und Wasserversorgungsleitungen durch Berstlining" (2004-07)

[27] GW 322-1 „Grabenlose Auswechslung von Gas- und Wasserrohrleitungen – Teil 1: Press – Ziehverfahren" (2003-10)

would have to assume a renewal rate of 1.5 % in order to be able to maintain a consistent standard with regard to the supply security and operating safety. Given that the supply industry is currently reporting renewal rates of 0.1 to 0.5 %, the demands on the maintenance of existing pipeline networks will inevitably constantly rise.

Steel pipelines with cathodic protection offer not only the general opportunity to locate defects and carry out quality control after laying, but also the opportunity to carry out constant monitoring of the pipes and pipeline network. If there is no opportunity to implement such a condition-based maintenance system, rehabilitation planning will only be possible using the the more schedule-based maintenance concept, which also requires service life statistics to be generated. How much statistics such as these can tell us is considerably dependent on how many different applications, laying and operating conditions and types of pipe system can be distinguished from the given dataset. The technological stages described here and their chronological arrangement are intended to provide assistance in this matter.

However, steel piping is not solely a subject of rehabilitation but is also used for the trenchless renewal of pipelines as it is commonly used today. The flexibility in the design of joining techniques, the various coating and lining designs and especially the defining mechanical properties allow trenchless techniques to be used cost-effectively to rehabilitate pipes.

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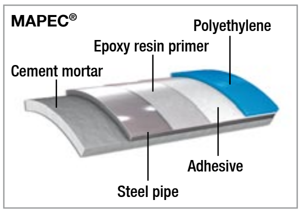

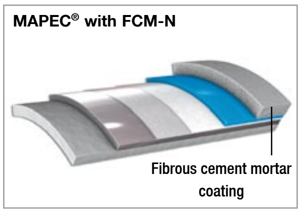

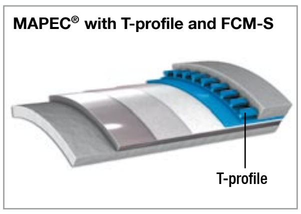

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