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Relining of pipe systems: conditions, benefits and application through case-study

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Abstract – **Relining is one of the best alternatives available today for pipe system rehabilitation. This trenchless solution is particularly interesting for urban agglomerations, as a smaller diameter pipe is pushed or pulled through the old pipeline. Relining creates a leak-tight "pipe within a pipe" system, which is as good as new in both structural and hydraulic terms. Relining can be performed with both circular and special, non-circular (NC) profiles. The latter is especially advantageous for the rehabilitation of old sewers, many of which were constructed in a variety of ovoid-like shapes. This paper presents the typical steps that are performed for pipeline rehabilitation with non-circular profiles, as well as an applied case study (a project implemented in the city of Würzburg in Germany).**

Keywords* – *pipeline rehabilitation, urban areas, relining, trenchless, non-circular.

1. INTRODUCTION

Much of the water pipe infrastructure in European cities is outdated and requires frequent maintenance and repair. European market potential for pipe rehabilitation was estimated at 2,5 - 3,5 billion € per year, equivalent to about 20.000 km of pipe that will need intervention in the next years [1]. In the USA, the needed funding is estimated at up to 325 billion $ for the next 20 years [2].

Digging up and replacing old underground pipeline systems is one of the most expensive choices and may cause significant disruptions to the landscape, with aggravating conditions in larger urban areas. The total cost for water pipes rehabilitation includes both direct costs and social costs (which are difficult to quantify) resulting from traffic delays, public inconvenience and effects on the environment [3]. A cost-effective solution to this problem is pipe rehabilitation or

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replacement with trenchless solutions. Some of the most relevant aspects to consider include state of the existing pipeline, static load capacity, variable pipe lengths, custom cross-section shapes, various jointing systems, hydraulic capacity, corrosion resistance, abrasion resistance, installation challenges (easy handling, without significant traffic or landscape disruptions, installation irrespective of weather conditions) as well as ensuring a long service life after intervention.

Trenchless methods include: “relining” (a smaller diameter pipe is pushed or pulled through the old pipeline), “close-fit lining” (the liner pipe is mechanically deformed or folded and after insertion is returned to the original form by application of heat or pressure), “spray-on” (lining applied to a cleaned and dried host pipe wall), “pipe bursting” (a larger diameter pipe than the old pipeline is installed with the help of a hydraulic pipe cracker which gradually brakes the old pipe open), “cured liner” (insertion of impregnated liner and cured with water or steam) or “cement mortar lining” (cement lining applied to a cleaned and dried host pipe wall) [4].

2. THE RELINING METHOD

Relining (slip lining) has been used since the mid twentieth century and is one of the most cost effective trenchless renewal systems [5]. A smaller diameter pipe is pushed or pulled through the old pipeline. Relining creates a leak-tight “pipe within a pipe” system, which is as good as new in both structural and hydraulic terms. The loss in flow area may be compensated by lower friction loss. Thus, although slip lining decreases the total cross sectional area of a culvert, using a smoother pipe material with a smaller Manning’s Roughness coefficient may compensate this issue [6].

The method presents considerable advantages: the old pipeline is rehabilitated quickly and easily and the client benefits from a pipeline that is of the same quality as a new one. In addition, the remaining annular space between the host and liner pipes is usually filled with pressure-resistant grouting consisting of a mixture of binding materials. This fixes the inserted pipe in position and can take over the structural load capacity. See Figure 1 for a sectional diagram depicting the old host pipe as well as the new liner pipe and the annular space.

In addition, slip lining does not require excavation except at selected locations and therefore it offers many benefits compared with replacement or repair using the open-cut method (less traffic disruption, less disturbance to the environment, and less disruption for the public) [7]. For example, in the case study presented in this paper there was only one entry pit for the rehabilitation of a 875-meter section. Even if the installation site provided limited storage conditions due to its location within the city, with efficient organization measures the rehabilitation works initially scheduled for nine months were completed within three months.

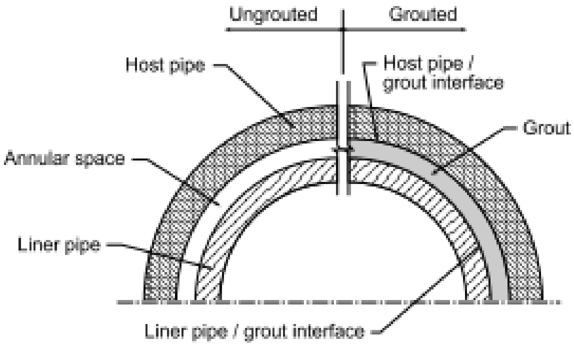

Fig. 1 Section with host pipe and new liner pipe [7]

Typical materials used in water distribution systems are steel, concrete, ductile iron, polyvinyl chloride (PVC), polyethylene (PE), high density polyethylene (HDPE) and glass reinforced plastic (GRP). GRP relining pipes are particularly suitable for pipe rehabilitation, as they are light in weight, corrosion resistant, easy to install and resist the load from the grouting. GRP is manufactured as a composite of wound glass fibers, resin, filler, and sand applied in either a centrifugal process or a winding type process. Relining can be performed with both circular and special, non-circular (NC) profiles. A typical non-circular glass reinforced plastic (GRP) profile is depicted in Figure 2.

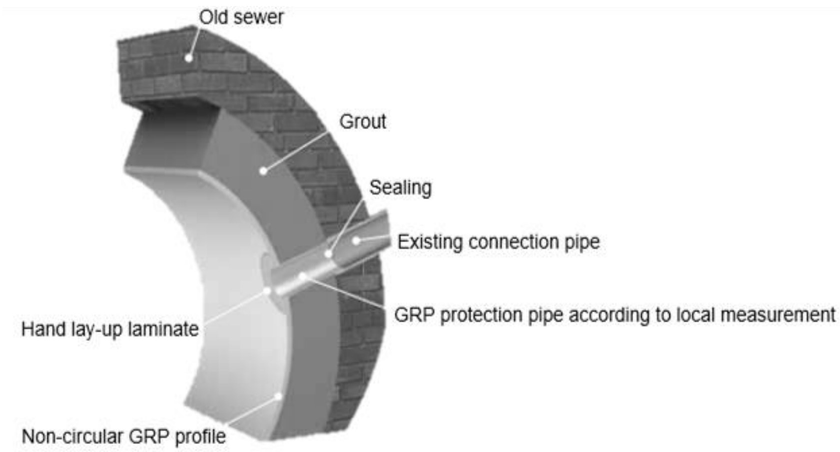

Fig. 2 Non-circular section with host pipe and new liner pipe [8]

Non-circular systems are particularly suitable for rehabilitation of corroded sewer lines. The pipes can be designed for specific loads and project requirements, while also taking structural dimensions, technical specifications and regulations regarding chemical resistance into account.

In addition to classic cross sections, such as circular, egg, jaw, or kite-shaped pipes, further combinations of shapes may be prepared to fit the condition of the old sewer. A suitable jointing technology is then selected: where shapes are completely convex, pipes are usually joined with push-on couplings, while for combinations of convex and concave or even shapes glued or laminated joints are typical. Suitable shafts and tangential manholes may be also considered to obtain a complete system including pipes with special cross-sections, lateral connections and manholes. This offers a lot of flexibility in terms of pipe system rehabilitation.

The typical steps to evaluating and implementing a rehabilitation project with non-circular profiles are: (i) assessment and static examination of the old sewer, (ii) cleaning of the old pipeline, (iii) calibration activities, (iv) installation, (v) lamination for connections to adjacent pipes and shafts, (vi) insulation of the ring area and (vii) pressure test of the pipeline.

Reference standards and technical rules include the newly published standard ISO 16611 for non-circular GRP pipes and joints, EN 752 "Drain and sewer systems outside buildings (Part V: Rehabilitation)", EN 1610 "Construction and testing of drains and sewers". For example, EN 752 differentiates between "rehabilitation" (complete process of reconstruction), "repair" (localized adjustment of damage), "renovation" (improvement of functionality) and "renewal" (construction of new pipelines that overtake the function of the previous ones). Pipelines should be tight, efficient in terms of water flow, safe to operate and chemically resistant [9].

For relining the first step (i) is to perform a condition assessment and static examination of the old sewer. As shown in Figure 3 below, three situations are considered: (I) the old pipe system is still viable, (II) the old pipe system is still viable with some defects (i.e. lengthwise fissures, small degree of pipe deformation with functional side bedding) and finally (III) the old pipe system is no longer viable. In cases where the necessity of a new profile is certain, the expected statics of the new profile and determination of wall thickness can be performed by means of dedicated computer programs (i.e. Finite Elements FEM calculations).

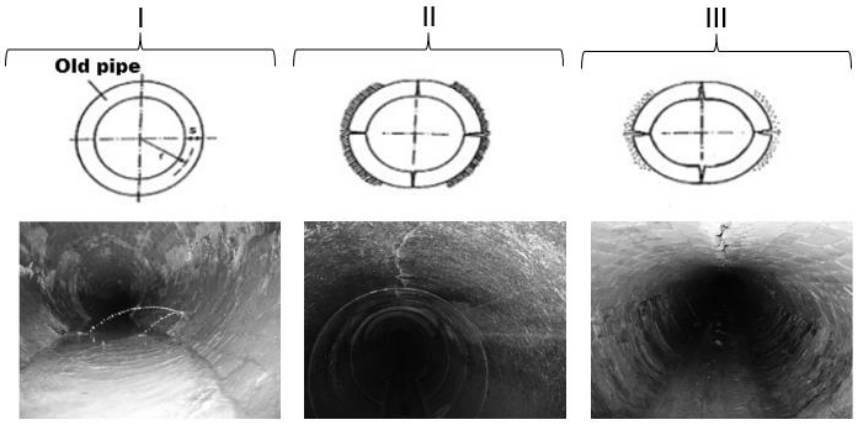

Fig. 3 Static examination of the old sewer [10]

Once the calculations are complete, the second typical step (ii) is the cleaning of the old pipeline, followed by the third (iii) calibration step.

Calibration can be performed manually or digitally. In case of manual calibration, no digital image is needed and a calibration model can be constructed (see Figure 4).

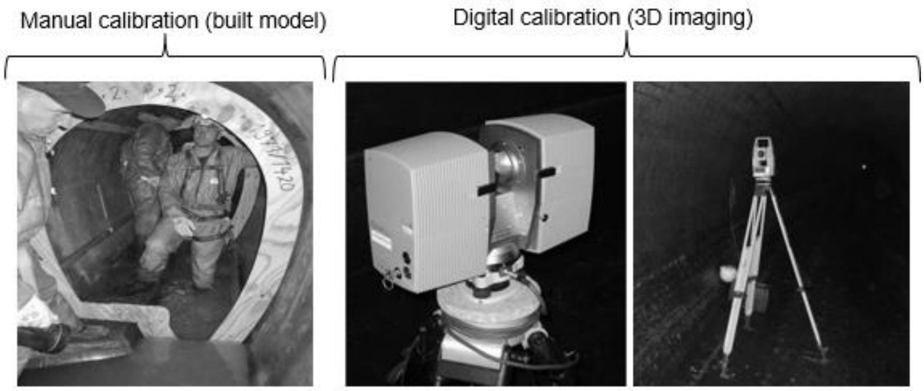

Fig. 4 Calibration models

The cross section of the model can be adjusted to a reasonable degree to match the old sewer. In case of digital calibration, the acquisition and representation of structures in three-dimensional space represents best practices and may bring significant benefits. For example, with help of non-contact measurement technology, old structures need to be entered only to a small extent, as compared with the manual calibration method. In addition, an extremely high measuring point density provides an excellent image of the geometry of the channel. With digital calibration, a 3-D image of the old sewer is generated and cross sections across the old pipeline can be defined as basis for the installation plan. Pipes can then be set-up in a defined sequence, per the local conditions and installation plan.

The next typical step (iv) is the installation of the pipes. This includes further activities such as production of the pipes per defined specifications, preparation of the construction site (i.e. digging of installation pits if necessary), transport and set-up of pipes within the old pipeline. Protocols of the pipe profiles, wall thickness measurement, length, optical appearance are customarily filled-in before and after installation. The profile of the pipe can be specifically adapted to the required local conditions (see Figure 5).

The next steps are (v) lamination for connections with adjacent pipes and shafts, followed by (vi) insulation of the annular area between the old and new pipelines. Typical requirements for the insulation are a strength of 5 N/mm2, high fluidity, low-shrinkage and sand-free. Insulation is processed layer by layer on subsequent sections.

Although grouting is not obligatory, performing this step may bring additional benefits such as increased resistance to buckling when the pipe is dewatered, increased resistance to shear failures at lateral connections, enhanced protection of the liner pipe in the event of host pipe failure and longer service life of the liner due to load sharing [11].

Fig. 5 Example of pipe profiles for relining [8]

The final typical step is (vii) a pressure test of the system. Tests are usually performed per EN 1610 “Construction and testing of drains and sewers” [12].

3. CASE STUDY: RELINING PROJECT IN WÜRZBURG, GERMANY

Wastewater in the town of Würzburg flows through a 540-km-long and over the centuries extended sewer system. The collector main collector (1.9 km) was in some areas more than 100 years old. In 2013 investigation of the status of the channel was organized and a restoration plan was subsequently devised. A section of 875 meters was identified in need of immediate rehabilitation [13]. The damage included corrosion, leaks and infiltration, which was facilitated by the proximity of the River Main. Many of the fittings for ventilation were cracked and there were deposits at the bottom of the main sewer.

Re-lining with GRP pipes was considered the best solution for this section in terms of sustainable rehabilitation and long service life after intervention. Building a new channel did not represent an economic alternative due to the location, depth and dimensions of the collector. The investment included rehabilitation with new profiles, calibration measurements and alignment to the adjacent shafts as well as renovation of connections to the larger water system.

The egg-shaped brick sewer had no standard dimensions, but a special cross-section of 1400 x 2250 mm. Non-circular profiles 1260 x 2110 mm were used which reduced the diameter of the liner pipe with approximately 16% than that of the old pipe. Flow capacity is one of the major factors to be considered in the design of slip line rehabilitation. The outside diameter of the liner pipe is usually at least 10% smaller than the inside diameter of the host pipe [7]. However, even with 16% reduction, the hydraulic requirements could still be fulfilled. This represented a paramount condition, due to the proximity to the waste water treatment plant and to the average rainfall of about 600 mm/year.

Prior to the start of the actual rehabilitation works, the old sewer profile was digitized with a 3D laser scanner. The resulting three-dimensional image of the channel served as basis for the installation plan. The scanning of the profiles was performed with up to 50 000 dots per second. At the same time, an integrated camera assured a photographic depiction of the profiles. The length of the pipe segments was determined by the local conditions. The maximum length was limited by the size of the installation pit or by the curves of the channel. Short lengths were necessary in curvature areas. In addition, the position of the connecting lines was considered in relation to the profiles' lengths, so that no connection would come directly in the pipe sleeve areas. These considerations were included in the installation plan and profiles were assigned sequential numbers so that delivery and installation on site could be performed „just-in-time". In addition, manual calibration of the structure was also performed with a custom-built calibrating model to have a simulation of the entire pipeline. The non-circular pipe wall was built up by means of filament winding.

A total of 401 non-circular profiles in lengths of 1 to 2.35 m and with a wall thickness of 25 mm were used in the rehabilitation of the old sewer [13].

The installation works were conducted from one single pit, which is why 533 m of pipe were installed in flow direction and another 342 m to the opposite direction. In the areas of manholes and special structures, the GRP profiles were cut open per the manhole dimensions to create accesses and emergency exits. Then, the pipes were connected with push-to-fit couplings using a coupling device and secured against buoyancy by means of spacers. The annular space of 3 cm was grouted. Connections to pipes and shafts in the system were laminated. Nine months had been scheduled for the implementation of this project. Thanks to the continuous coordination of all parties involved, the installation was completed within 3 months, after no more than one third of the designated construction time.

4. CONCLUSIONS

Water loss in distribution systems represents a relevant cost factor for municipalities as well as a waste of a critical resource (especially in areas where water is scarce). Much of the existing infrastructure in Europe requires frequent maintenance and needs rehabilitation.

Digging up and replacing old underground pipeline systems is often an expensive choice, with aggravating conditions in urban areas (i.e. disruptions to traffic and to the landscape). Trenchless methods usually provide a more cost and time effective solution. Among trenchless rehabilitation methods, relining with non-circular pipe systems based on glass fiber reinforced plastics is particularly suitable for outdated and corroded sewer lines and provides a high corrosion resistant pipeline solution for many decades.

The study-case further indicates that identification of the rehabilitation solution is based on multiple of factors: state of the existing infrastructure, location, specific needs based on the structural integrity of the section requiring remedial action, potential for contaminants to enter the pipe system as well as cost efficiency of the rehabilitation and of the operation of the pipeline.

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