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# MECHANICAL STUDY ON REHABILITATION OF PIPELINES BY GUNITE COVERING

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**Abstract:** Most utility networks, such as: gas, water, sewerage, industrial lines, heating, are outdated; defects and exfiltration occur more often, which for safety and economic reasons have to be quickly repaired. For such situations, the so-called "No dig" technology – rehabilitation without excavation, has been applied with increasing frequency during recent years. This technology, presented in this paper, consists of inserting a composite material tube impregnated with a reactive resin (selected according to the pipe's use) into the pipe to be rehabilitated. After inserting the tube into the pipe, the tube is subject to polymerisation, consequently producing a new pipe of superior quality. The method is applicable to pipe with diameters ranging between Dn 100mm – Dn 2000mm and length up to 600.00 m.
**Key words**: lining, pipe rehabilitation, "No dig" technology.

## 1. INTRODUCTION

For pipelines still capable of transport, either under pressure or by gravity, interior lining is the most advanced rehabilitation method. The technology originated in Japan where frequent earthquakes are causing damages, cracks and exfiltration in pipelines.

Technology developed in very short time and is currently one of the most efficient rehabilitation methods for gas, oil, drinking water, waste water and industrial water pipelines.

Rehabilitation of damaged pipelines should comply with the following requirements: satisfy needs; conform with specifications; low cost for a particular use; capacity to meet a need; complete satisfaction of beneficiaries; product's social utility level.

Defective products would cause, as expected, dissatisfaction to the customer. They are also costly for everybody, as the errors have to be identified and corrected, and the customers indemnified.

All these costs could be reduced (or eliminated) if the quality would be improved by reducing or eliminating deficiencies.

High quality leads to increased revenues in two ways: attract new customers, thus increasing market share; increase prices along with quality improvement.

Using quality instruments helps to identify the root cause(s) of certain problems. When the root cause is eliminated, the deficiency would be significantly reduced or even eliminated.

## 2. „NO DIG" REHABILITATION TECHNOLOGY

An increasingly used technology for pipeline rehabilitation during recent years is the so-called "No dig" technology, rehabilitation without excavation. The main "No dig" technologies are the following:

- lining with "composite tubing" – "Liner";
- lining with special concrete – "Shotcrete" (concrete covering the pipe inside);
- rehabilitation by "Pipe Bursting" method;
- rehabilitation by "Pipe in Pipe" method.

The "Liner" rehabilitation method consists of inserting a composite tube inside the pipe to be rehabilitated.

The “Shotcrete” concrete rehabilitation consists of pipe reinstatement on the inside with corrosion protection and covering cracks and holes with size up to 3 mm. Cementing product is prepared as prescribed, a mixture of cement, sand and additives, in specified ratios. The procedure is to apply this cement on the entire pipe’s interior surface. The material has good adhesion to pipe walls and behaves very well at temperature variations. The technology is simple to be put in practice and provides good rehabilitation.

The “Pipe Bursting” technology consists of forcedly inserting a cone shaped “bursting head” which breaks and shatters the old pipe pushing it outwards. At the same time the new pipe is pulled along the old pipe’s route. Pulling is performed by a winch or using pulling rods. All work is performed using a special access pit.

Another rehabilitation method is the “Pipe in pipe” relining method. This is applicable to all types of pipes and consists of inserting a GRP tube inside the old pipe. Due to the characteristics of GRP pipes, this method provides quick and reliable rehabilitation, with improved hydraulic characteristics in the new pipe.

## 3. „NO DIG“ TECHNOLOGY BY GUNITE COVERING

First stage in the pipe rehabilitation with lining is the ***video inspection*** inside the pipe, in order to identify defects locations, to evaluate their size and also to determine the rehabilitation method to be applied.

Visualisation is performed using a robot with a fixed video camera, for pipes ranging between 100mm and 300mm, while for pipes larger than 300mm two robots with more efficient X-ray cameras are being used.

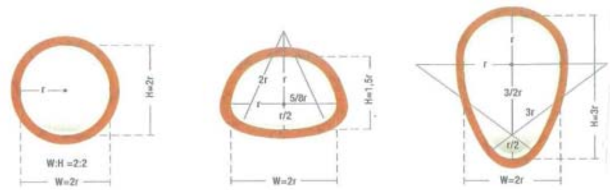
Next stage is cleaning with a high pressure water jet. The cleaning process is filmed, recorded on CD or DVD and presented to the customer. Based on visual records, the pipe condition may be carefully assessed to identify the rehabilitation measures to be applied.

The most frequently used cleaning method is called “jet pipe cleaning”, an environment friendly method ensuring removal of all corrosive substances, foreign objects etc.

Sewerage pipes and collectors forming the sewerage network have to comply with certain conditions required by the quality of waste water, hydraulic characteristics of flow, pipe laying – either on or underground, soil conditions and costs.

Pipes for gravity operated sewerage are made of concrete, reinforced concrete, cast iron, ceramic, PREMO etc, while for pressurised sewerage are made of reinforced concrete, cast iron, steel, PREMO and composite materials.

Pipes (closed sewers) collecting and transporting domestic waste water, rain water or operating as a combined system are made of tubes with various cross sections. The most usual cross sections of sewerage pipes are the following:




a) Circular profile Dn 150mm-Dn2000mm  b) Arch profile  c) Inverted egg- shaped 200/300mm- 900/1350mm

Fig. 1 Usual cross sections of closed sewers

Waste water flow rate in residential areas is determined according to the provisions of the general urban planning, taking into account the consumer categories: domestic, public, industrial, street cleaning and green areas watering.

As per standard STAS 1846 /1996 “Determination of sewerage flow rates” the domestic waste water flow rate is calculated with the formula:

$$Q_{domestic} = Q_{h\,max}\ [l/s] \tag{1}$$

where:

$Q_{h\ max}$ – hourly maxim flow rate calculated as per SR – 1343/2006

$$Q_{h\,max} = \frac{N_i \times q_{spec} \times K_{day} \times K_h}{24 \times 3600}[l/s] \tag{2}$$

where:

$N_i$ – number of residents

$q_{spec}$ - specific cold and hot water demand

[l/person x day]

$K_{day}$ – daily variation coefficient of water flow rate on demand categories, depending on available sanitary installations.

$K_h$ – hourly variation coefficient of water flow rate, determined by number of residents in each pressure zone.

Flow rate calculated with formula **(1)** represents the **actual flow rate $Q_{ef}$** passing through the sewerage section used for calculation and for sizing the domestic sewerage network, with a profile as per fig. 1.

Rain water flow rate will be determined taking into account the following aspects:

- geographical location, which gives the maximum rainfall intensity, as per STAS 9470 "Maximum rainfall";
- variation of time interval between rain fall; when such interval is short (frequent rain) the soil is already saturated with water, thus for new rain more water would be collected to sewerage;
- types of surfaces receiving rain water; rain falling on buildings roofs is practically collected entirely, while rain falling in green areas drains to sewerage in small amount;
- buildings importance class in populated areas.

As per STAS 1846 "Determination of sewerage flow rates", rain water flow rate is calculated with the formula:

$$\mathbf{Q_{rain} = m} \times \mathbf{S} \times \mathbf{Ø} \times i \quad \mathbf{[l/s]} \qquad \mathbf{(3)}$$

where:

**m** – flow reduction coefficient, takes into account the sewerage storage capacity within the locality;

**S** – basin area for the collecting sewer [ha];

**Ø** – drainage or permeability coefficient;

**I** – rain intensity for calculation measured in l/s x ha as given in STAS 9470.

Sewerage in combined systems (transporting domestic waste water together with rain water) is sized for **full section** (fig.1), however it will be checked if $\mathbf{Q_{domestic}}$ ensures **self-cleaning velocity** of **0.7m/s.**

Tube lining (liner) procedure can be used to rehabilitate sewerage pipes made of reinforced concrete, plain concrete, ceramics, PVC, PE and cast iron. Liner structure is presented in figure 2.

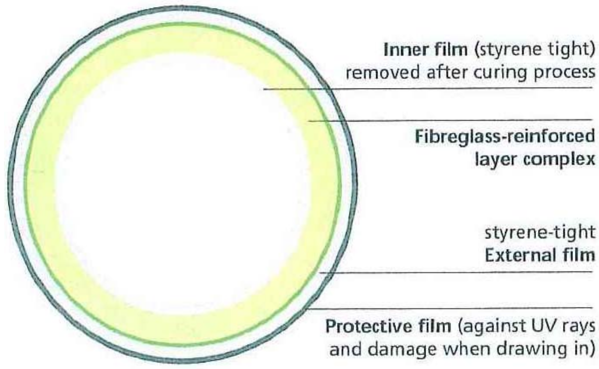



Fig. 2 Liner structure

Liner and rehabilitation procedure will be selected according to the following:

- pipe location;
- fluid transported in the pipe – drinking water, domestic water, rain water or combined system;
- construction and hydraulic characteristics of the pipe;
- pipe degradation level in static conditions.

Lining procedure requires two access pits: an insertion pit and a reception pit; selected liner shall withstand pulling force; liner is inserted inside the pipe with a traction cable winch (Fig.3 [5]). In the figure there are:

1-Use of a sliding film for easier insertion of the liner before the beginning of an installation

-Assembly of packing at the head of the liner

-Insertion of the liner using a winch

2-Assembly of packing at the end of the liner;

-Assembly of connection pipes and temperature sensors between the packing and steam generator/UV installation

3-Calibration of a SAERTEX-LINER, using compressed air, until it has reached the optimum fit against the walls of the existing sewer.

-Curing as detailed in the installation instructions.

4-Curing is followed by the removal of the packing at the liner ends in the manholes

-Removal of the inner film

-Closeness/tightness test of the laminate if required

-Opening of lateral connections giving fast function take of pipeline and sewerage network.

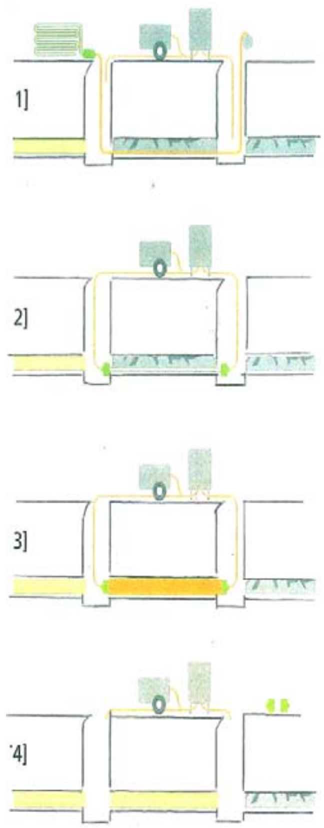



Fig. 3. Liner insertion method in pipelines

Pipe rehabilitation using the **"NO DIG"** procedure consist of inserting the liner (of various materials) in the old pipe, then using polymerisation technologies to adhere the liner to the pipe's inside surface.

Polymerisation can be achieved by applying: thermal treatment with steam; thermal treatment with hot water; UV light treatment; special resins; air pressure treatment.

Lining is applicable for rehabilitation of circular section pipelines with diameters ranging between Dn 100mm – 3400 mm, or ovoid section pipelines ranging between 200mm/300mm - 900mm/1350 mm.

## 4. SELECTION OF COMPOSITE POLYMER MATERIALS USED FOR LINING

Main requirements for composite materials used for pipe rehabilitation are as follows: high elasticity at high temperatures of the agent transported in the sewer; good adhesion to the rehabilitated pipe walls; corrosion resistance over time; good capacity of filling holes/cracks of various sizes; ensure pipe water tightness (protection against infiltration and exfiltration); capacity to take static loads; structural strength (capacity to form a structurally independent new pipe inside the existing old pipe).

Composite materials selection will be based on the following criteria [5]:

By pipelines usage: for sewerage in combined systems, rain water sewerage, domestic sewerage; for pressure pipes.

By composite material composition: fibre glass reinforced resin; textile with PP or PE layer; Uliner – memory liner.

## 5. STATIC CALCULATIONS RELATED TO REHABILITATION OF PIPELINES AND SEWERS

Prior to performing pipe rehabilitation, calculations will be made regarding the main tension forces $\mathbf{s_r}$ $\mathbf{s_a}$ exerted on the pipe, due to exterior pressure "$p_e$" and interior pressure "$p_i$".

A unit length will be detached from a constant cross-section long tube with internal diameter 2a and external diameter 2b, subject to interior pressure "$p_i$" and exterior pressure "$p_e$" (Fig. 4).

Pipe material shall be deemed to comply with Hooke's law and the bending effect shall be ignored. Location of a certain point M in the cross section shall be defined in polar coordinates, namely polar radius "r" and angle "θ" from the horizontal. Around point M a tube element shall be considered having dimensions dr and rd**θ** (Fig. 5).

Length of side 1-2 is variable with quantity:

$$(r+u)\,d\theta - r d\theta = \mathbf{u}\,d\theta \qquad (4)$$

From this geometrical aspect of tube element deformation, there is the equation for the specific radial length $\mathbf{e_r}$ and circumferential length $\mathbf{e_a}$:

$$\mathbf{e_r} = \frac{(dr+u+du-u)-dr}{dr} = \frac{du}{dr} \qquad (5)$$

$$\mathbf{e_a} = \frac{(dr+u+du-u)-dr}{dr} = \frac{du}{dr} \qquad (6)$$

Equations (5) and (6) give specific lengths related to unknown radial deformation "u" of point M.

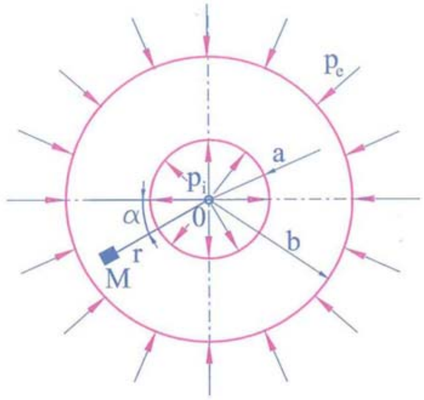



Fig. 4 Tube loads diagram

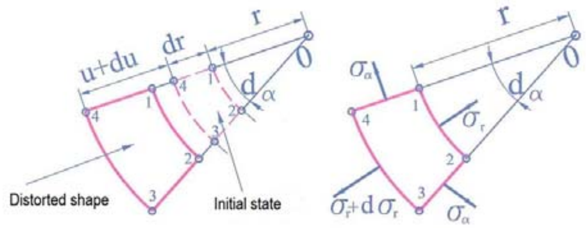



Fig. 5 Unit element for calculating specific length $e_r$ and $e_a$

Specific lengths have normal tensions with radial and circumferential orientations. Thus, at the location of point M a radial tension $s_r$ and a circumferential tension $s_a$ occur. These tensions are exerted on the element's sides. Due to symmetry, tensions $s_a$ on the element's laterals have to be equal, however $s_r$ on side 1-2 differs with an elementary quantity from the tension on side 3-4. Consequently the radial and circumferential directions are the main stress directions.

Relation between main tensions and specific lengths is given by the Hooke's general law. For the plane tension there are:

$$s_r = \frac{E}{1-\mu^2}(e_r + m e_a) = \frac{E}{1-\mu^2}\left(\frac{du}{dr} + m\frac{u}{r}\right);$$
$$s_a = \frac{E}{1-\mu^2}(e_a + m\, e_r) = \frac{E}{1-\mu^2}\left(\frac{u}{r} m \frac{du}{dr}\right) \quad (7)$$

As the tube is static, elementary forces on the element's sides are balanced. From this static aspect a balance equation for the elementary forces projection is obtained (Fig. 5):

$$(s_r + ds_r)(r+dr)da - s_r\, r\, da - 2\, s_a\, dr \sin\frac{d\alpha}{2} = 0 \quad (8)$$

After disregarding small infinites of superior order and approximating the sine with the radian angle, the result is a differential equation with two unknowns $s_r$ and $s_a$ :

$$\frac{d}{d}(r s_r) - s_a = 0 \quad (9)$$

For solving equation (9) the formulas for main tensions (7) are applied. The substitution gives:

$$\frac{d^2u}{dr^2} + \frac{1}{r}\frac{du}{dr} - \frac{u}{r^2} = 0 \quad (10)$$

Differential equation (10) contains a single unknown, the radial displacement "u". After integration, equation (10) becomes:

$$\frac{d}{dr}\left(\frac{du}{dr}\right) + \frac{d}{dr}\left(\frac{u}{r}\right) = 0$$
$$\frac{d}{dr}\left[\frac{1}{r}\frac{d}{dr}(ur)\right] = 0 \quad (11)$$

By integrating equation (11) the result is:

$$u = A\, r + \frac{B}{r} \quad (12)$$

where A and B are integration constants.

With this solution, the tension formulas (7) become:

$$s_r = \frac{E}{1-\mu^2}\left[A(1+m) - \frac{B}{r^2}(1-m)\right]$$
$$s_a = \frac{E}{1-\mu^2}\left[A(1+m) + \frac{B}{r^2}(1-m)\right] \quad (13)$$

Sum of main tensions $s_r$ and $s_a$ is constant, independent of point's location:

$$s_r + s_a = \frac{2EA}{1-\mu} = \text{const.} \quad (14)$$

Consequently the specific length on the longitudinal axis direction is:

$$e_x = -\frac{\mu}{E}(s_r + s_a) = \text{const} \quad (15)$$

Integration constants A and B are determined considering that radial tension $s_r$ on the interior and exterior surface equals the applied pressure:

$$s_r = -p_i \text{ , for } r = a$$
$$s_r = -p_e \text{ , for } r = b; \quad (16)$$

In these conditions equation (13) becomes:

$$-p_i = \frac{E}{1-\mu^2}\left[A(1+m) - \frac{B}{a}(1-m)\right]$$
$$-p_e = \frac{E}{1-\mu^2}\left[A(1+m) - \frac{B}{b^2}(1-m)\right] \quad (17)$$

The solution of equation system (17):

$$A = \frac{1-\mu}{E}\,\frac{a^2 p_i - b^2 p_e}{b^2 - a^2};$$
$$B = \frac{1+\mu}{E}\,\frac{a^2 b^2 (p_i - p_e)}{b^2 - a^2} \quad (18)$$

By substituting constants A and B in equations (12) and (13) the equations of radial displacement of point M and of main tensions around this point are:

$$u = \frac{1-\mu}{E}\frac{a^2 p_i - b^2 p_e}{b^2-a^2} r + \frac{1+\mu}{E}\frac{a^2 b^2}{r}\frac{p_i - p_e}{b^2-a^2} \quad (19)$$

$$s_{a,r} = \frac{a^2 p_i - b^2 p_e}{b^2-a^2} + \frac{a^2 b^2}{r^2}\frac{(p_i - p_e)}{(b^2-a^2)} \quad (20)$$

## 6. CONCLUSIONS

**Advantages** of the "NO DIG" technology are: lower final costs; very short execution time; very low noise pollution during the execution of works; no additional works; very good water tightness along the rehabilitated pipe section; very good roughness coefficient.

**Disadvantages** of this technology are:

"NO DIG" technology is applicable only in certain locations; transport capacity of the existing pipe cannot be increased; if counter-slopes are encountered along the existing pipe, the liner will follow their shape.

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**STUDIU MECANIC DE REABILITARE A CONDUCTELOR PRIN CĂMĂŞUIRE**


**Rezumat**: Cele mai multe reţele de conducte, cum ar fi: gaz, apă, canalizare, reţele tehnologice, reţele de termoficare, sunt îmbătrînite şi din ce în ce mai des se produc defecte şi scurgeri, care din motive de siguranţă şi economie trebuie rapid remediate. Pentru aceste situaţii, s-a impus în ultimii ani, din ce în ce mai mult, aşa numita tehnologie „NO DIG“, reabilitare fără săpătură. Această tehnologie prezentată în lucrare, constă în introducerea unui tub compozit impregnat cu o răşină reactivă (aleasă în funcţie de destinaţia conductei ), în interiorul conductei care urmează a se reabilita. După introducerea tubului în conductă, acesta este supus procesului de polimerizare, în urma căruia se obţine o nouă conductă cu calităţi superioare. Metoda se poate aplica la conducte cu diametre cuprinse între Dn 100mm – Dn 2000mm şi lungimi de până la 600,00m.



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