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THE MECHANICAL CHARACTERISTICS OF COMPOSITE MATERIALS USED FOR THE REHABILITATION OF CANALS BY MEANS OF LINING

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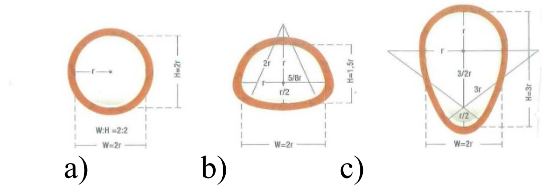
Abstract: The innovative and fast method of rehabilitation of old canals is the "NO DIG" technology. It consists in the insertion of a hose of composite material (liner) in the body of the old tube, a procedure called lining. In order to make the correct choice of liner, we need to know the extent of the damage and the defects of the old tube. These defects are due to the loads and the stress under which the tube has been during its operation and can be categorized into three fundamental state of static damage. For each state it is necessary to perform a static calculation, based on which the technical and structural characteristics of the liner which will be used for lining will be established. The mechanical stress to which the old canal tube is being exposed consists of: soil pressure, traffic pressure, pressure of ground water, water in the tube; for these sorts of stress there will also be made a static calculation of the future composite material (liner), with the specification that this liner will be exposed in the laboratory to additional mechanical stress: tearing, compression, torsion and traction.
Keywords: composite material, liner, mechanical characteristics, canal tube.

1. INTRODUCTION

The tubes (closed canals) collecting and transporting the wastewater mainly consist of tubes of simple or reinforced concrete with different sections. The most common canal sections are: circular, arch and inverted egg-shaped (Fig.1).



a) b) c)

a) Circular profile
b) Arch profile
c) Inverted egg- shaped
Dn 150mm -Dn2000mm
Dn500/750mm - 800/1200mm

Fig.1 Common sections of closed canals

These tubes, being laid at great depths of 2.00-4.00 m, on roads with heavy and intense traffic, are exposed to mechanical loads and stress. In time, these degrade the structure of the canals and implicitly lead to infiltration of ground water and exfiltration of wastewater. Old tubes that have reached these states of degradation cannot function anymore at high performance hydraulic parameters.

The most advanced method of rehabilitation of such tubes is lining, consisting of the introduction of a composite liner in the body of the old tube without stripping. For the application of this technology it is necessary to know the stress to which the old tube is being exposed, as well as its state of degradation, in order to establish the type and the mechanical characteristics of the composite material.

2. MECHANICAL LOADS AND STRESS TO WHICH THE OLD CANAL TUBES WHICH ARE TO BE REHABILITATED BY MEANS OF LINING ARE BEING EXPOSED

The loads which act on the old canal tubes can be categorized as follows [5]:

Fundamental loads

a. Permanent loads

- soil pressure above the canal;
- soil pressure without overload (horizontal pressure);
- mathematical interior and exterior water pressure.

b. Overloads

- loads due to the vehicles in traffic;
- loads due to temporarily deposited materials on the canal route.

Accidental loads

- interior water pressure due to functioning of the tube under pressure.

Consecutively we will present these loads.

Soil pressure above the canal

This pressure is given by the weight of the soil above the canal; its value depends on the laying depth and on the nature of the soil (clay, dry humus, wet and water saturated humus, etc.).

Soil pressure without overloads (horizontal pressure)

Experiences have shown that the horizontal pressure on canals laid in the ground has an insignificant value. It is much less than the one which would be established by use of usual formulas for the soil displacement.

Mathematical interior and exterior water pressure

This pressure is being introduced in the calculations because of two hypotheses:

- the canal works with gravitational water (with free surface of the water)
- the canal works under pressure

With the first hypothesis, the water pressure is being considered a fundamental load. It is being applied perpendicularly on each element of the interior surface of the canal, its dimension being from zero in the upper part to the maximum value determined by the height of the canal in the lower part.

With the second hypothesis, over the effect of the water pressure, determined under the first hypothesis, the interior pressure is also being added, being equal to the height of the upper generator of the canal up to ground level, but not more than 0,5 at. This pressure is being considered an accidental load.

Overloads

These overloads are being applied on the surface of the soil. Their action on the canals is being analyzed based on the elasticity theory, considering the earth a homogenous and isotropic elastic semi-space.

In case of action of more forces on the surface of the soil, the resulting tension on an underground tube at a certain depth is given by the sum of the action of each force in accordance to the principle of the overlaying of effects.

For tubes which are laid at sufficiently great depths the influence of overloads is much reduced.

For tubes laid at very little depths (0.8-1.0m) these overloads affect the bearing structure of tubes of simple or reinforced concrete.

Stress appearing in the walls of canal tubes of simple or reinforced concrete

The transversal section of monolith canals being circular with a closed contour, it is undetermined in three ways from a static standpoint.

The unknowns are being determined by the methods of the construction mechanics, considering that the concrete portion of the canal works in the elastic stadium.

Due to the symmetry of the loads and the symmetry of the transversal section of the canal in relation to the vertical axis going through the center of gravity of the section, the number of unknowns can be reduced to two.

All of the above loads together with the environmental factors (aggressiveness of the ground water and the soil) to which the canal tubes are being exposed lead in time to their degradation.

3. MECHANICAL STRESS TO WHICH THE COMPOSITE MATERIAL (LINER) USED FOR THE REHABILITATION OF OLD TUBES BY MEANS OF LINING IS BEING EXPOSED

The rehabilitation of old tubes by means of lining consists of the introduction of a liner of composite material in the old tube; through various technologies, the liner will adhere to the inner surface of the old tube. Due to its structure, the liner will take over all mechanical loads to which the old tube (host) is being and will be exposed.

The liner is a composite material from: matrix (different types of resins), reinforcing material (glass or textile fiber) and an auxiliary material.

Composite materials are anisotropic and have very different properties depending on the composition, the nature of the components, the adherence between phases and their morphology.

Depending on the type of the components (matrix, reinforcing material and auxiliary material) it is possible to obtain very flexible or very rigid materials, with high resistance to cranking, traction, shocks, etc.

Liner is a composite material produced from a filamentary reinforcement material, embedded in a structural matrix. The matrix as well as the reinforcing material can be of metallic, mineral or organic nature, but their conception presumes complementarity and compatibility. Each component has an essential and well established role in the conception of the final material (liner).

The reinforcement material (hardener), by the structure of its skeleton, confers mechanical resistance to traction, cranking and torsion, while the matrix ensures the connection of the fibers of the hardener as well as their protection, the improvement of the mechanical properties, especially the improvement of the compression resistance of the composite material.

The most important mechanical characteristic of a composite material used for the rehabilitation of canals by means of lining is the resistance to tearing. When a composite material tears, it becomes obvious that one element of its structure cannot fulfill its role.

Some of the causes for tearing of a composite material are:

- microfissuring of the matrix under the action of mechanical loads, residual tensions, under wet or aging conditions;
- fissuring of the matrix which leads to the tearing of the composite material;
- exfoliation of the fiber when the connection between the fiber and the matrix is not produced properly.

The tearing ratio of a composite material is [1]:

$$R = \frac{\text{Limit tension}}{\text{Applied tension}} \qquad (1)$$

- when **R > 1** - the applied tension is lower, the composite material resists;
- when **R < 1** - the applied tension is higher, the composite material does not resist to the loads.

The mechanical stresses to which a composite material used for the rehabilitation of tubes by means of lining is being exposed are:

Resistance to longitudinal compression

Some fibers resist very little to compression and can break in two ways. The first way occurs when the percentage of the reinforcing fibers in the matrix is higher and the matrix resists to shearing, and the second way occurs when the percentage of the reinforcement is lower than 30%, in which case the matrix resists to traction and compression. In conclusion, the resistance to compression of a composite material depends on the characteristics of the matrix, on the reinforcement percentage and the resistance to compression of the fibers.

Resistance to transversal compression. With this type of stress, the tensions induced in the matrix and the fibers are equivalent. The fibers are always more resistant than the matrix.

The criteria for the tearing of composite materials [1]

The criteria for the tearing of composite materials are of empirical nature and are similar to the ones used for metallic materials. They rely on experimental data.

The most common criteria for tearing are:

- the criterion of maximum deformation;
- the Tsai- Wu- Tsai criterion [1]

The criterion of maximum deformation

Within this criterion, tearing occurs when the deformation in a certain main direction is equal to the corresponding maximum deformation produced by the axial compression, shearing and stretching.

The Tsai- Wu- Tsai criterion

This criterion is a relatively new theory, ensures the possibility of interpreting the resistance to complex stress for materials with different values of resistance to compression and stretching.

4. THE BEHAVIOR OF COMPOSITE MATERIAL TUBES UNDER MECHANICAL STRESS

Stress on the tubes under torsion by ovalization

The cranking of the tubes leads to ovalize of the straight sections. The rigidity to cranking drops due to the instability process.

Stress on the tubes under external pressure (fig.2)

Considering a tube of length **L** which undergoes external pressure, with a radius **r** and the wall thickness **e**, the critical pressure is given by the relation [1]:

$$P_{critical} = 0.8\frac{E_y}{1-0.1\frac{E_x}{E_y}}\sqrt[4]{\frac{E_x r_0}{E_y\, L}\left(\frac{e}{r_y}\right)^{\frac{5}{2}}}$$

where: E – the elasticity module

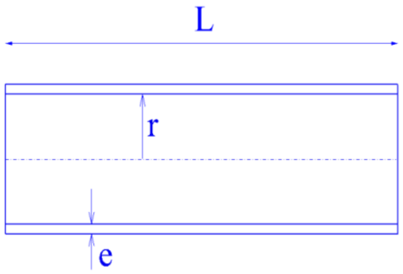


Fig.2 Tube under external pressure

The deformation of composite material tubes are influenced by the architecture of the reinforcing materials as well as by their nature. It is recommended to set the reinforcing material at a certain angle in relation to the generator of the tube.

Stress on the composite material tubes under cranking (fig.3)

In the laboratory, pieces of the tube and of the samples of the liner which will be used in the lining process undergo several mechanical stresses in order to check their structure. In the following we will enumerate the most important ones of these stresses:

i)Stress on the composite material tubes under cranking

It is considered that a composite material tube is undergoing cranking (fig.3). On this tube a force F is acting while the tube is being supported by two bearers. Starting from the calculation of the plane samples (fig. 4) we will calculate the uniform stress under cranking and the module of resistance to cranking.

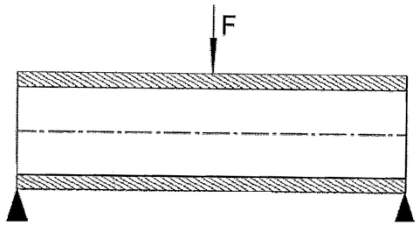


Fig. 3 Composite material tube undergoing cranking

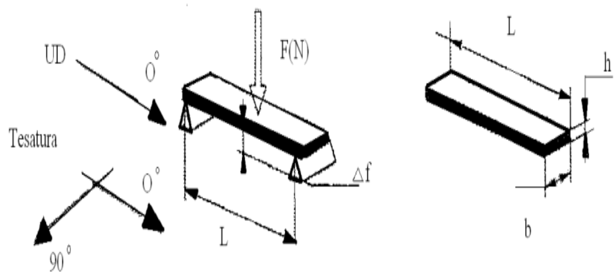


Fig.4 Plane samples of composite material undergoing cranking

where: F – is the force acting on the samples
h – is the thickness of the samples
b – is the width of the samples
L – is the length of the samples

The maximum cranking momentum M_{max} for the plane samples is given by the relation:

$$M_{max} = \frac{FL}{4} \quad (2)$$

The module of resistance to cranking is given by the relation:

$$W_{Znec} = \frac{M_{max}}{\sigma_a} \quad (3)$$

For tubes, the module of resistance to cranking W_Z is given by the relation:

$$W_Z = \frac{\pi(D^4 - d^4)}{32D} \quad (4)$$

where: D – is the exterior diameter of the tube
d – is the interior diameter of the tube

Replacing relation (4) in the relation (3) leads to the relation of the uniform stress σ under cranking for tubes:

$$\sigma = \frac{8FLD}{\pi(D^4-d^4)} \quad (5)$$

The uniform stresses are being checked in relation to the maximum admissible stress σ_{adm} specific to each type of composite material and helps us to dimension the tubes depending on the maximum cranking momentum and the elasticity module for cranking.

$$\sigma_{ef} = \frac{M_{max}}{W_{zef}} \leq \sigma_{adm} \quad (6)$$

ii)**The calculation of composite material tubes stressed under traction** [1]

A composite material tube undergoing traction is being considered (fig.5). No internal or external pressure is acting on this tube. Starting from the calculation of the plane samples undergoing traction (fig.6), we can write the relation of the uniform stress:

$$\sigma = \frac{F}{bh} \quad (7)$$

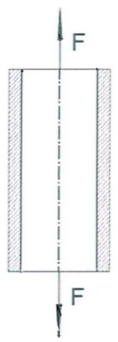


Fig.5 Composite material tube undergoing traction

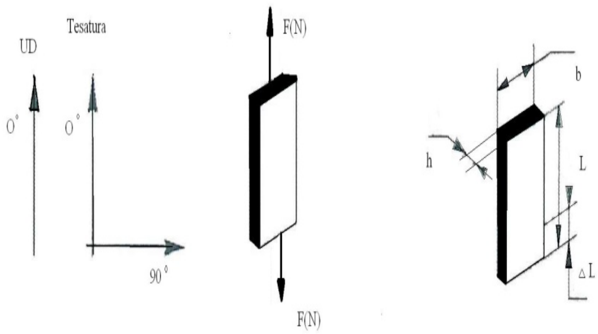


Fig.6 Plane samples from composite material undergoing traction

where: F – is the force acting on the samples
h – is the thickness of the samples
b – is the width of the samples
L – is the length of the samples
DL – is the relative linear extension

The elasticity module E in longitudinal direction is given by the relation:

$$E = \frac{FL}{bh\Delta L} \quad (8)$$

For tubes, the uniform stress is:

$$\sigma = \frac{F}{A} \quad (9)$$

where: A – is the surface of the circular sections

Replacing A in the relation (9) leads to the relation of the uniform stress:

$$\sigma = \frac{4F}{\pi(D^2-d^2)} \quad (10)$$

The relative linear extension DL is being deduced from the relation:

$$A = \frac{4FL}{\pi\Delta L(D^2-d^2)} \quad (11)$$

and from the relation (11) leads to the relation:

$$\Delta L = \frac{4FL}{\pi A(D^2-d^2)} \quad (12)$$

5. STATES OF STATIC DEGRADATION DUE TO MECHANICAL LOADS WHICH OLD CANAL TUBES UNDERGO

Defects occurring during the operation of the canals are caused by: fissures, caving, colmation, perforations, corrosions, erosions, etc. or by wear due to the long operation time.

On tubes with high wear there will be infiltrations and exfiltration, caused by the following:

- the tubes being of simple concrete corrode at very high rates of flowing speed due to the time since their construction up to present time;

- the joints between the tubes have not been executed properly, which in time led to decentering and displacement of the tubes;
- the joints between prefabricated tubes are destroyed;
- due to the fact that some canals have not been reinforced, fissures and cracks occur in their structure;
- the aggressiveness of the transported wastewater produces interior corrosions.

All these defects caused by the loads and stresses the old canal tube undergoes can be categorized in three fundamental states of static degradation [7]:

State I – the tube has leaks at the joints, the tube has self-supporting capacity;
State II – the tube has longitudinal fissures with reduced deformation of the lateral parts (capable of functioning), the tube has self-supporting capacity;
State III – the tube has visible deformations, displacement of sleeves, ring fissures, large cracks of the sleeves, missing sections of the tube, in which case the tube cannot function anymore and special calculations are necessary, the tube has no more self-supporting capacity.

Depending on the three above mentioned states, the thickness and the liner suited for the rehabilitation of the old pipe by means of lining are being selected. For tubes with a diameter ≤ Dn 250 and of PVC, PP, PEID, belong to state I and the following conditions are being met simultaneously: no pressure in the tube and no underground water, the static check of these is not necessary.

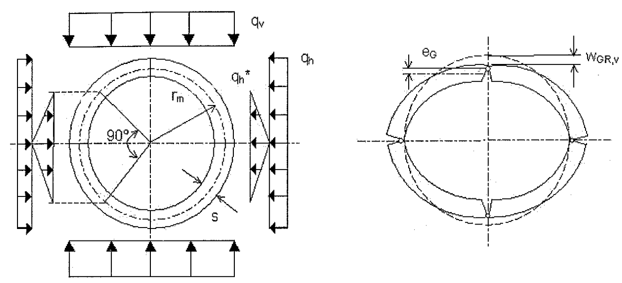
The static verification of the host tube for the three states is being made in the following loading hypotheses:

States I and II with the following loading hypotheses:
- ground water pressure;
- own loading, in case of diameters > 800 mm;
- water pressure in the tube;
- thermal effects.

For the states I and II, given the exterior pressure of the underground water p_a , it is recommended to use rigid liner.

State III with the following loading hypotheses:
- loadings of soil and traffic, acting on the old tube (fig. 5);
- ground water pressure;
- water pressure in the tube;
- own loading of the tube;
- thermal effects.

For state III, given an overload q_v, in order to assure the stability of the tube and its safe operation it is recommended to use flexible liner.



a) undeformed tube b) deformed tube

Fig.7 Soil and traffic loads which the old tube undergoes when in degradation state III

Where: q_v- is the vertical pressure of the soil on the tube (state III) [kN/m^2]

q_h - is the horizontal pressure of the soil on the tube (state III) [kN/m^2]

r_m- is the average radius of the old tube [mm]

s - is the thickness of the wall of the old tube [mm]

e_G - is the eccentricity of the articulation of the old tube [mm]

W_{GRIV} - is the deformation of the articulated ring of the old tube [mm]

For the calculation of the cranking momentum of the liner under the action of the exterior forces, the pressure p_a of the exterior water (states I and II of the old tube) or for the calculation of the cranking momentum of the liner under the load q_v of the soil and q_h of the traffic (state III of the old tube), an important role is held by the main characteristic regarding the deformability (rigidity) of the material.

This measure of rigidity of an elastic and isotropic model is called Young's Module (E), also known as the longitudinal elasticity module. It is defined as the relation between the axial tension and the axial deformation in the validity domain of Hooke's Law.

The more "rigid" a material is, the higher the value of the module of elasticity E is.
The module of elasticity has the same units of measure as the tensions, i.e. [N/mm^2] or [MPa].

In order to assure a sufficient minimum rigidity of the liner, the water pressure is considered, independent of the height of the ground water, as being:

h = D + 0,1m but no less than h = 1,5m,
where:

h – is the height of the water above the peak of the old tube

D – is the exterior diameter of the old tube

The special cases for which rigorous static calculations are being made are the following:
- large ring fissures or large cracks in the sleeves, in which case a calculation is made according to the theory of the thin linen;
- missing sections of the tube, in which case a calculation is made according to the theory of the thin linen;
- displacement of the transversal and longitudinal sleeves, caused by tearing of the tube;
- presence of nicked areas and holes in the walls of the tube;

For the static calculation, irrespective for which state of degradation of the old tube, the following data is needed:
- the material and the thickness of the wall of the old tube;
- the nature of the soil, the thickness of the layer covering the tube, the maximum/minimum height of the underground water);
- the detection of the defects on the old tube (breaks, caving, colmation, perforation, corrosion, erosion, etc.) by means of preliminary video inspection.

6. CONCLUSIONS

The mechanical stresses which the old canal tube undergoes in time are: the pressure of the soil, the pressure of the traffic, the pressure of the ground water, of the water in the tube; for these stresses there will be also made the static calculation for the future composite material (liner), under the specification that this liner will undergo further mechanical loads in the laboratory: for tearing, compression, torsion and traction.

All defects due to loads and stresses which the old canal tube undergoes can be categorized in three fundamental states of static degradation [7]:
State I – the tube has leaks at the joints, the tube has self-supporting capacity;
State II – the tube has longitudinal fissures with reduced deformation of the lateral parts (capable of functioning), the tube has self-supporting capacity;
State III – the tube has visible deformations, displacement of sleeves, ring fissures, large cracks of the sleeves, missing sections of the tube, in which case the tube cannot function anymore and special calculations are necessary, the tube has no more self-supporting capacity.

For the states I and II under an exterior pressure p_a of the underground water it is recommended to use a rigid liner with a higher elasticity module E.

For the state III under an overload q_v, in order to assure the stability of the tube and its safe operation it is recommended to use flexible liner with a lower elasticity module E.

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CARACTERISTICILE MECANICE ALE MATERIALELOR COMPOZITE FOLOSITE PENTRU REABILITAREA CANALELOR PRIN CĂMĂŞUIRE

Rezumat: Metoda inovatoare şi rapidă de reabilitare a canalelor vechi este tehnologia „NO DIG”. Aceasta constă în introducerea unui furtun din material compozit (liner) în corpul conductei vechi, procedeu numit cămăşuire.

Pentru alegerea corectă a liner-ului, trebuie să cunoaştem starea de degradare şi defectele conductei vechi. Aceste defecte se datorează încărcărilor şi eforturilor la care a fost supusă conducta în timpul funcționării sale şi pot fi clasificate în trei stări fundamentale de degradare statică. Pentru fiecare stare este necesar a se realiza calculul static, în urma căruia se vor stabili caracteristicile tehnice şi structurale ale liner-ului care urmează a fi utilizat pentru cămăşuire.

Solicitările mecanice la care este supusă, în timp, conducta de canal veche sunt : presiunea pământului, presiunea din trafic, presiunea apei freatice, apei din conductă, pentru aceste solicitări va fi realizat şi calculul static al viitorul material compozit (liner) , cu specificarea că acest liner va fi supus în laborator unor solicitări mecanice suplimentare : la rupere, compresiune, torsiune şi tracțiune.

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