Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XV, 2026
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

STATE-OF-THE-ART APPLICATIONS FOR THE REHABILITATION OF IRRIGATION MAIN-CANAL CROSSINGS

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Abstract

The main irrigation infrastructure in Romania includes numerous underpasses of the main canals built of prestressed concrete or large-diameter metal pipes. After decades of operation, these structures show advanced degradation, such as cracks, corrosion, and leaks, leading to water losses and reduced hydraulic efficiency. Their location under roads and other types of infrastructure makes traditional replacement and dismantling of existing pipes difficult, highlighting the need for trenchless rehabilitation technologies. This article analyzes the applicability of CIPP (Cured-In-Place Pipe) technology for the rehabilitation of culverts in irrigation systems, based on experience in the maintenance of urban water supply and sewerage networks. It presents the steps leading up to the intervention, including inspection and structural assessment, as well as the principles of liner manufacturing, highlighting the specific limitations of large diameter pipes. It also addresses the general methodology for designing liner thickness in accordance with international standards and technical criteria relevant to water conveyance systems. The installation process is analysed in terms of operational requirements and equipment, highlighting the advantages of no-dig technologies in restricted-access areas. The results demonstrate the potential of CIPP as a sustainable and hydraulically efficient solution for irrigation infrastructure modernisation in Romania.

Key words*: Cured-In-Place Pipe (CIPP), hydraulic efficiency, irrigation canal crossings, no-dig rehabilitation, water loss reduction.*

INTRODUCTION

Irrigated agriculture is essential for food security and stable agricultural production in the face of climate variability. Water use efficiency plays an increasingly important role in maintaining agricultural production in the context of rising temperatures, changing precipitation patterns, and intensifying extreme weather events, which continuously affect the availability of water resources for irrigation (Dai et al., 2018; Vogel et al., 2019; Mirzabaev et al., 2023; Farah et al., 2025).

In Romania, the main irrigation infrastructure includes an extensive network of main canals and underpasses made of concrete pipes or large-diameter metal pipes. After decades of use, these structures show significant deterioration, manifested by cracks, corrosion, and leaks, leading to significant water losses and reduced hydraulic efficiency of irrigation systems (Grumeza & Kepleș et al., 2005). These losses negatively affect water distribution to agricultural crops, reducing production potential during critical periods such as prolonged droughts (Totolea, 2024).

Traditional interventions for the rehabilitation of underground pipes involve significant excavations, which are disruptive from an economic and logistical point of view, especially in areas where crossings are located under roads or sensitive infrastructure elements. In this context, no-dig rehabilitation methods offer clear advantages by reducing the environmental impact and costs associated with open-cut works (Mocean et al., 2014).

One of the most widely used trenchless technologies is Cured-In-Place Pipe (CIPP), which consists of inserting and curing a reactive liner inside the existing pipe, creating a new pipe section without extensive excavation (Ji et al., 2020). This method is widely adopted in water and sewer networks due to its efficiency in rehabilitating damaged pipes and its ability to provide a continuous structural solution (Salem, 2008). However, the literature highlights

limitations and high design requirements for the mechanical performance of CIPP systems, underscoring the need for detailed assessments prior to application (Yang et al., 2021; Hu et al., 2023). This study investigates the structural and hydraulic feasibility of a large-diameter UV-cured CIPP installation applied to a severely deteriorated deep-buried gravity collector. Although based on an urban case study, the structural conditions - significant burial depth, high external loads, and advanced pipe degradation - are comparable to those encountered in irrigation canal crossings. By quantifying deformation limits, assessing the structural independence of the liner, and evaluating hydraulic performance before and after rehabilitation, the study provides a technical basis for assessing the transferability of CIPP technology to irrigation infrastructure.

MATERIALS AND METHODS

Case Study Description

The study is based on the rehabilitation of a large-diameter buried collector located in Botoșani, Romania (Figure 1). The investigated section had a total length of 125 meters and consisted of two geometrically distinct segments: an upstream ovoid reinforced concrete pipe 1200 mm constructed in the early twentieth century, and a downstream circular DN 800 mm section made of steel installed during a later intervention.

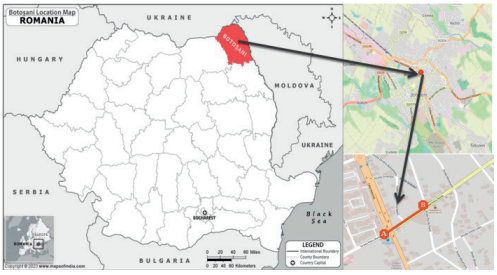


Figure 1. Location of the study- Romania, Botosani, Municipiul Botosani

The pipeline was located at a burial depth ranging between 5 and 6 m beneath a major traffic artery. CCTV inspection revealed severe structural degradation, including longitudinal cracking, wall perforations, loss of invert (radier) sections, joint misalignment, exfiltration, and evidence of soil erosion around the pipe. Sediment deposits exceeded 70% of the cross-sectional area prior to cleaning (Figure 2). Although the case study originates from an urban gravity collector, the structural conditions—large diameter, high soil cover, and advanced host pipe deterioration—are representative of buried irrigation canal crossings subjected to similar external loads.



Figure 2. Post-execution robotic CCTV inspection documentation

Rehabilitation System Description

Rehabilitation was performed using a UV-cured glass-fiber-reinforced polymer (GRP) CIPP liner (Figure 3). The liner thickness was:

- 10.5 mm for the ovoid section,
- 8.4 mm for the circular DN 800 section.

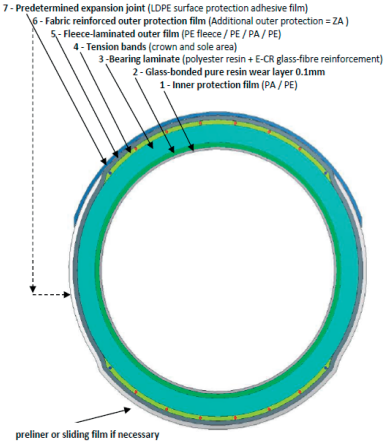


Figure 3. Cross-sectional geometry and liner configuration (Source: Brandenburger Liner GmbH & Co. KG, 2024)

The liner was designed to function as a fully structural liner, meaning it was assumed to carry

all external loads independently of the residual structural capacity of the host pipe.

Structural Assessment Methodology

The structural evaluation considered the following load components:

Soil load:

$$\sigma = \gamma \cdot H \quad (1)$$

γ = unit weight of soil (kN/m³)
H = burial depth (m)

Critical Buckling Resistance:

The critical external pressure for a circular liner embedded in soil was estimated using:

$$P_{cr} = \frac{2E}{(1-\nu^2)} \left(\frac{t}{D}\right)^3 \quad (2)$$

where:
E = short-term elastic modulus of GRP (MPa)
ν = Poisson's ratio
t = liner thickness (mm)
D = mean liner diameter (mm).

To account for long-term creep behavior:

$$E_{long} = \frac{E\ short}{\Phi} \quad (3)$$

where φ represents the creep reduction factor.

Deformation Verification:

The relative diametral deformation was calculated as:

$$\delta = \frac{\Delta D}{D} \cdot 100 \quad (4)$$

where ΔD represents the total diametral variation under load.

The calculated elastic deformation was compared against an admissible limit of 3%, consistent with standard trenchless rehabilitation practice.

The structural analysis of the CIPP liner was performed in accordance with DWA-A 143-2:2015-07, the technical reference used in addition to SR EN 13566-4.

Hydraulic Performance Evaluation

To assess the hydraulic implications of rehabilitation, discharge capacity was estimated using Manning's equation:

$$Q = A \cdot V = \frac{A}{n} \cdot R^{2/3}{}_h \cdot S^{1/2} \quad (5)$$

where:
V= average water velocity (m/s)
Q= Volumetric flow rate (m^3/s)
n = Manning roughness coefficient (Aged reinforced concrete: n = 0.016; GRP CIPP liner: n = 0.010)
A = flow area (m^2)
R_h = hydraulic radius (Rh =A/P)
S = hydraulic slope

Although liner installation slightly reduces internal diameter, the decrease in roughness can compensate for this geometric reduction.

Transferability Assessment Framework

In order to assess the applicability of the proposed approach to irrigation canal crossings, a comparative analysis framework was developed. It takes into account both the relevant differences and similarities between the two types of infrastructure, including external loading conditions (including potential traffic loads), internal hydraulic regime (gravity flow versus low-pressure operation), and operational model (continuous service versus seasonal operation).

This framework supports qualitative assessment of conditions under which structural and hydraulic findings can be extrapolated to irrigation systems.

RESULTS AND DISCUSSIONS

Structural Performance

The structural verification results for the UV-GRP CIPP liner installed in the ovoid (800 × 1200 mm) and circular (DN 800 mm) sections are summarized in Table 1.

The analysis considered a burial depth of approximately 5-6 m, with soil loads calculated using average unit weight values typical for compacted urban soils. The host pipe was conservatively assumed to provide negligible structural contribution, corresponding to a fully structural liner configuration.

Table 1. Results of static calculation

DEFORMATION PROOF LINER GEBRAUCHSLAST

Nr.crt.	*Parameter*	*Symbol*	*Value*	*Unit*
1	Clear width at springline height	b_s	800	mm
2	Clear height at crown–invert	h_s	1200	mm
3	Relevant diameter (percentage deformation)	d_v	1000	mm
4	Annular gap absolute (const. Value)	x_s	1.97	mm
5	Local imperfection (absolute)	w_s	9.56	mm
6	Global imperfection (absolute, one side)	wGR,v	0	mm
7	Elastic deformation (absolute, horizontal – E1)	$w_{esh,E1}$	10.41	mm
8	Elastic deformation (absolute, horizontal – E2)	$w_{esh,E2}$	-16.82	mm
9	Total elastic deformation (horizontal)	w_{esh}	27.23	mm
10	Relative elastic deformation	$\delta_{v,el}$	2.72	%
11	Allowable elastic deformation	$\delta_{v,el,adm}$	3	%
12	Total diameter deviation	w	36.79	mm
13	Relative total deformation	δ_v	3.68	%
14	Reference value for total deformation	$\delta_{v,A}$	10	%
15	Elastic deformation (absolute, vertical – E1)	$w_{esv,E1}$	1.57	mm
16	Elastic deformation (absolute, vertical – E2)	$w_{esv,E2}$	4.75	mm

The calculated relative elastic deformation for the ovoid section was 2.72%, remaining below the 3% admissible limit specified in SR EN 13566-4 for fully structural liners. When geometric imperfections were included, the total

relative deformation reached 3.68%, still significantly below the 10% reference threshold defined by DWA-A 143-2 (2015) for structural stability assessment in trenchless rehabilitation practice. After incorporating long-term creep effects through elastic modulus reduction in accordance with SR EN 13566-4 provisions, the verification remained within acceptable limits, confirming the adequacy of the selected liner thickness (10.5 mm).

For the circular DN 800 section (8.4 mm thickness), deformation values were lower due to the inherent structural efficiency of the circular geometry. Overall, under the assumed load conditions, the liner behaves as an independent load-bearing structure capable of compensating for severe host pipe deterioration, including partial invert loss.

Hydraulic Performance

The hydraulic implications of rehabilitation were assessed using Manning's equation under identical slope conditions before and after lining. Assuming representative roughness coefficients:

- Aged reinforced concrete: n = 0.016
- GRP CIPP liner: n = 0.010

Table 2 presents the hydraulic parameters calculated before and after rehabilitation. Although the installation of the lining resulted in a minimal reduction (1 cm thickness around the circumference) in the cross-sectional area for the ovoid section (from 0.754 to 0.721 m²), the significant decrease in the Manning roughness coefficient led to a substantial increase in discharge capacity, from 0.626 m³/s to 0.768 m³/s (+22.68%).

Table 2. Hydraulic parameters before and after CIPP rehabilitation under gravity flow conditions

Nr. crt	Parameters	Section	
		Ovoid 1200 mm	Circular DN 800
Concrete/steel			
1	Area A (m²)	0.754	0.502
2	Wetted Perimeter (m)	6.34	3.87
3	Manning n	0.016	0.013
4	Hydraulic Radius Rh (m)	0.142	0.2
5	Flow rate Q (m³/s)	0.626	0.641
CIPP			
1	Area A (m²)	0.721	0.783
2	Wetted Perimeter (m)	6.21	3.14
3	Manning n	0.01	0.01
4	Hydraulic Radius Rh (m)	0.116	0.196
5	Flow rate Q (m³/s)	0.768	0.726

A similar improvement was observed for the circular DN 800 conduit, where discharge increased by 13.26% following roughness reduction. Overall system capacity increased by 15.89%, as illustrated in Figure 4.

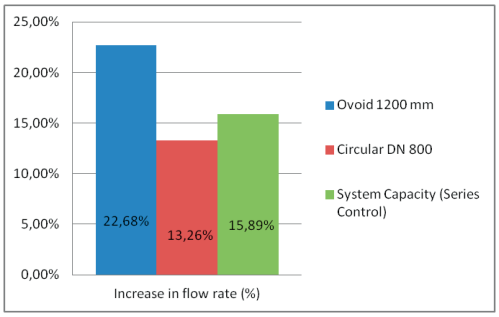


Figure 4. Percentage increase in discharge capacity after rehabilitation

These results indicate that, under uniform gravity flow conditions, the reduction in internal roughness has a stronger influence on conveyance capacity than moderate variations in hydraulic diameter. The smoother internal surface decreases frictional losses, producing a net hydraulic gain despite minor geometric contraction.

It should be noted that the analysis assumes steady uniform flow and does not account for transient effects or sediment transport processes, which may influence field performance.

Structural Implications for Irrigation Crossings

The structural results demonstrate that a UV-GRP liner with thickness between 8.4-10.5 mm can sustain external soil loads corresponding to burial depths of up to 6 m without exceeding deformation limits.

Compared with published experimental and numerical studies on CIPP-rehabilitated concrete pipes, the deformation values observed in this study fall within the lower range of reported results for fully deteriorated host pipes. This supports the assumption that, under similar soil cover conditions, the liner can provide sufficient structural reliability independent of the host pipe.

However, culverts crossing intubated irrigation channels in areas where they pass under roads and valleys (siphons) may have different operating and loading conditions compared to

gravity sewer collectors, particularly due to potential internal pressures in siphon-type culverts and seasonal filling and emptying cycles.

Hydraulic Considerations in Irrigation Systems

Post-rehabilitation hydraulic performance is primarily governed by internal surface smoothness (Figure 5). In deteriorated concrete conduits, increased roughness and sediment accumulation significantly reduce flow capacity. Under gravity-driven conditions, lowering Manning's coefficient from 0.016 to 0.010 can produce measurable reductions in energy losses and corresponding gains in conveyance efficiency.

In large-scale irrigation systems, even moderate hydraulic improvements may enhance downstream reliability and reduce pumping requirements, implicitly leading to lower energy consumption for pump operation. However, in pressurized irrigation systems, head losses due to high roughness cause friction that must be evaluated under maximum flow conditions using the Darcy-Weisbach equation.

Consequently, the hydraulic advantages demonstrated in this study are directly applicable mainly to the crossings of piped irrigation channels in gravitational operation.



Figure 5. Condition of DN 800 mm pipeline before and after lining

Transferability Assessment

Based on the comparative framework developed in the methodology, the transferability of UV-CIPP rehabilitation from sewer systems to culvert crossings can be considered technically feasible under conditions characterized by burial depths comparable to or less than 6 m, gravity or low-pressure flow regimes, the absence of significant transient loads, and the performance of a complete structural verification including long-term creep effects.

However, applicability becomes conditional in situations involving sustained internal pressures or transient stresses exceeding the typical regime of gravity-fed collectors, in which case an additional structural analysis is required that includes the combined effects of internal pressure and external loads.

This article is based on a single case study with a large diameter, operated in a gravitational regime, and the effects of internal pressures specific to irrigation siphons have not been investigated, but by applying the similarity method, this rehabilitation method can also be successfully applied to similar objectives in irrigation facilities. Consequently, although structural and hydraulic feasibility under significant external loads has been demonstrated, further research including pressure regimes and long-term monitoring is needed to consolidate the generalization of the results to a wider range of irrigation infrastructure configurations.

CONCLUSIONS

This study demonstrates the structural and hydraulic applicability of UV-cured CIPP technology to large-diameter buried pipes, representative of culvert crossings for irrigation. Structural verification at burial depths of 5–6 m showed that the UV-GRP liner, designed as a fully structural system, maintained relative deformation below the 3% admissible limit, even when long-term modulus reduction was considered. The liner therefore provides sufficient resistance to external soil loads without reliance on host pipe integrity.

Hydraulically, the reduction in internal roughness generated an 8–15% increase in conveyance capacity despite minor diameter reduction. Under gravity-driven conditions, this corresponds to lower friction losses and improved flow efficiency.

The results indicate that UV-CIPP rehabilitation can be technically transferred to gravity-operated or low-pressure irrigation crossings, provided that burial conditions and internal pressure limits are verified. For pressurized or transient regimes, additional structural assessment is required.

Overall, trenchless UV-CIPP represents a structurally reliable and hydraulically advantageous alternative to open-cut replacement in irrigation infrastructure modernization.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support provided by S.C. Blueco Waste S.R.L. and Brandenburger Anwendertage for making available the technical documentation and practical information related to the CIPP rehabilitation works. The authors also thank all specialists involved in the implementation of the case study for their technical support and valuable contributions to this research.

REFERENCES

Brandenburger Liner GmbH & Co. KG. (2024). Brandenburger Liner BB2.5 – Technical Data Sheet (Version 001, 24 May 2024). BurrowTech. https://burrowtech.co.nz/wpcontent/uploads/2024/07/Brandenburger-Liner-BB2.5.pdf

Dai, A., Zhao, T. & Chen, J. (2018). Climate Change and Drought: a Precipitation and Evaporation Perspective. *Curr Clim Change Rep 4*, 301–312 https://doi.org/10.1007/s40641-018-0101-6

European Committee for Standardization (CEN). (2011). *EN 13566-4:2011. Plastics piping systems for renovation of underground non-pressure drainage and sewerage networks - Part 4: Lining with cured-in-place pipes*. CEN.

Farah, A.A., Mohamed, M.A., & Musse, O.S.H. (2025). The multifaceted impact of climate change on agricultural productivity: a systematic literature review of SCOPUS-indexed studies (2015–2024). *Discov Sustain,* 6, 397, https://doi.org/10.1007/s43621-025-01229-2

German Association for Water, Wastewater and Waste (DWA) (2015). *DWA-A 143-2: Rehabilitation of drainage and sewer systems outside buildings - Part 2: Static calculation for the renovation of drainage and sewer systems using lining and assembly methods*. DWA.

Grumeza, N., & Klepeș, C. (2005). *Amenajările de irigații din România* [Irrigation Systems in Romania], Bucharest, Editura Ceres.

Hu, L., Zhang, B., & Yang, K. (2023). Numerical Study on Mechanical Properties of Corroded Concrete Pipes before and after Cured-in-Place-Pipe Rehabilitation. Sustainability.; 15(11):8586. https://doi.org/10.3390/su15118586

Ji, H.W., Koo, D.D., & Kang, J.-H. (2020). Short- and Long-Term Structural Characterization of Cured-in-Place Pipe Liner with Reinforced Glass Fiber Material. International Journal of Environmental Research and Public Health. 17(6):2073. https://doi.org/10.3390/ijerph17062073

Mirzabaev, A., Bezner Kerr, R., Hasegawa, T., Pradhan, P., Wreford, A., Tirado, C., von der Pahlen, M., & Gurney-Smith, H. (2023). Severe climate change risks to food security and nutrition. *Clim Risk Manag*. 39: 100473. https://doi.org/10.1016/j.crm.2022.100473.

Mocean, F., Achimas, G., Morar, T., & Achimas, S. (2015). Mechanical study on rehabilitation of pipelines by gunite covering. Acta technica napocensis-Series: Applied mathematics, Mechanics, and Engineering, 57(2).

Salem, S. (2008). Use of Trenchless Technologies for a Comprehensive Asset Management of Culverts and Drainage Structures, Project 07-15, Midwest Regional University Transportation Center College of Engineering.

Totolea, I. B. (2024). Cercetări privind viabilitatea tehnico-economică a amenajării de irigaţie pentru plantaţii pomicole în cadrul SC Livada mere de Iteşti, judeţul Bacău [Research on the Techno-Economic Feasibility of an Irrigation Development for Fruit Orchards at SC Livada Mere de Iteşti, Bacău County] (Doctoral dissertation, "Ion Ionescu de la Brad" University of Life Sciences, Iaşi).

Vogel, E., Donat, M.G., Alexander, L.V., Meinshausen, M., Ray, D.K., Karoly, D., Meinshausen, N., & Frieler, K. (2019). The effects of climate extremes on global agricultural yields. *Environ Res Lett.*; 14(5): 054010. https://doi.org/10.1088/1748-9326/ab154b.

Yang, K., Fang, H., Bu, J., Zhang, X., Li, B., Du, X., & Zhang, Z. (2021). Full-scale experimental investigation of the mechanical characteristics of corroded buried concrete pipes after cured-in-place-pipe rehabilitation. Tunnelling and Underground Space Technology, 117, 104153.