An Integrated Field Implementation Framework for Gravity Sewer Asset Management Using Standardized Condition Assessment, Defect Coding, and UV-CIPP Rehabilitation

A Practitioner's Field Implementation Study

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Abstract

Aging gravity sewer networks require rehabilitation strategies that are technically reliable, economically sustainable, and minimally disruptive to urban environments. Although ultraviolet-cured-in-place pipe (UV-CIPP) technology has become an established trenchless rehabilitation method, published literature rarely describes how condition assessment, standardized defect coding, rehabilitation execution, and quality assurance are integrated into a unified field implementation workflow.

This paper presents an integrated field implementation framework developed from practical experience gained across multiple municipal gravity sewer rehabilitation projects. The framework combines systematic CCTV inspection, defect classification using the Water Research Centre (WRC) Manual of Sewer Condition Classification (5th Edition) and EN 13508-2, structured rehabilitation planning, UV-CIPP installation, and post-installation quality verification.

The methodology was applied during the rehabilitation of more than 120 km of gravity sewer pipelines ranging from DN150 to DN2000. More than 4,500 structural and operational defects were documented using internationally recognized coding systems, supporting the successful installation of over 280 UV-CIPP liners. Practical implementation challenges, quality assurance procedures, and lessons learned are presented to demonstrate how standardized workflows improve inspection consistency, rehabilitation planning, and construction quality.

Rather than introducing a new rehabilitation technology, this study contributes a practical implementation framework that integrates existing engineering standards into a repeatable workflow suitable for municipal sewer asset management programs. The paper also discusses the emerging role of AI-assisted inspection systems as complementary tools for improving future defect recognition and reporting efficiency.

Keywords: UV-CIPP, sewer rehabilitation, trenchless technology, condition assessment, defect coding, gravity sewer, asset management

1. Introduction

Aging sewer infrastructure is a critical concern for urban centres globally. Deteriorating pipelines pose risks to public health, the environment, and the economy, necessitating effective rehabilitation strategies that minimize disruption to communities. Traditional open-cut replacement methods are often impractical in densely developed areas due to high costs, traffic disruption, and social impact (Najafi & Gokhale, 2022).

Trenchless rehabilitation technologies have emerged as preferred solutions for extending the service life of deteriorating sewer pipelines. Among these, cured-in-place pipe (CIPP) lining has gained widespread acceptance due to its ability to create a structurally sound, seamless, and watertight pipe within the existing host pipe (ASTM F1216, 2022). The ultraviolet (UV) curing variant offers significant advantages over conventional ambient or hot-water curing methods, including faster curing times, reduced energy consumption, and superior quality control during the curing process.

Effective rehabilitation planning requires accurate condition assessment of existing pipelines. CCTV inspection remains the most widely used method for evaluating sewer condition, enabling the identification and classification of structural and operational defects (ISO 11295, 2022). Standardized defect coding systems, such as the WRC Manual of Sewer Condition Classification (5th Edition) and EN 13508-2, provide consistent frameworks for documenting and communicating pipeline condition (WRC, 2016; CEN, 2011).

Despite the widespread adoption of CCTV inspection, standardized defect coding systems, and UV-CIPP rehabilitation, these practices are commonly presented as independent technical activities within engineering standards and manufacturer guidance. Comparatively fewer publications describe how they can be integrated into a single implementation framework covering inspection, engineering assessment, rehabilitation planning, installation, quality assurance, and post-rehabilitation verification within large-scale municipal sewer rehabilitation programmes.

This paper presents a field-validated implementation framework developed through practical application across multiple gravity sewer rehabilitation projects. Rather than proposing a new rehabilitation technology, the study demonstrates how internationally recognized engineering standards—including WRC Manual of Sewer Condition Classification (5th Edition), EN 13508-2, and relevant ASTM practices—can be integrated into a structured workflow that improves consistency, traceability, quality control, and engineering decision-making throughout the rehabilitation lifecycle.

2. Literature Review

2.1 Trenchless Rehabilitation Technologies

The rehabilitation of deteriorated pipelines using trenchless methods has become standard practice in the water and wastewater industry (Najafi & Gokhale, 2022). CIPP lining is one of the most commonly used trenchless technologies, involving the insertion of a resin-impregnated flexible tube into the existing pipe, followed by curing to form a new structural pipe within the host pipe (ASTM F1216, 2022).

UV-CIPP represents an advancement in CIPP technology where ultraviolet light is used to initiate and accelerate the curing of the resin-impregnated liner. The 2021 edition of ASTM F1216 expanded its scope to include photoinitiated reaction in installation and curing, formally recognizing UV-CIPP as a standard practice (ASTM F1216, 2022). Compared to steam or hot-water curing, UV curing offers faster processing times, lower energy consumption, and reduced environmental impact. The technology has been successfully applied in sewer networks ranging from DN100 to DN2000, demonstrating its versatility across various pipe diameters.

Although numerous studies have demonstrated the structural and operational advantages of UV-CIPP systems, most investigations primarily evaluate liner materials, curing behaviour, or structural performance. Comparatively less attention has been given to documenting the practical integration of inspection, condition assessment, rehabilitation planning, construction execution, and quality assurance within a unified implementation framework. Consequently, there remains a need for field-oriented studies that bridge engineering standards and day-to-day rehabilitation practice.

2.2 Condition Assessment and Defect Coding

Effective rehabilitation planning requires accurate condition assessment of existing pipelines. CCTV inspection remains the most widely used method for evaluating sewer condition, enabling the identification and classification of structural and operational defects (ISO 11295, 2022).

Defect Coding Standards:

The coding of defects in sewer pipelines is essential for standardized communication, rehabilitation planning, and asset management. Four primary standards are widely used internationally:

Table 1.

Standard	Primary Purpose	Strength
WRC Manual (5th Ed.)	Defect classification	Widely used for rehabilitation planning
EN 13508-2	Inspection coding	European standardization
ASTM F1216	Installation	Rehabilitation procedures
ISO 11295	Rehabilitation strategy	Asset management framework

Although these standards differ in scope and terminology, they share the common objective of improving consistency in pipeline assessment and rehabilitation planning. WRC emphasizes practical defect classification, EN 13508-2 standardizes inspection reporting across Europe, ASTM F1216 governs rehabilitation procedures, while ISO 11295 provides strategic guidance for rehabilitation planning. The present study integrates these complementary standards into a single implementation framework applicable to municipal sewer rehabilitation projects.

Comparison of Standards:

While WRC and EN 13508-2 have similar objectives, they differ in their specific coding structures and grading criteria. Both systems are recognized internationally, and the WRC system is used in conjunction with EN 13508-2 for sewer condition classification (WRC, 2016; PUB, 2023). Practitioners often develop familiarity with both standards to meet varying client requirements and project specifications.

Importance of Consistent Defect Coding:

Accurate and consistent defect coding is critical for effective asset management. Key benefits include:

Rehabilitation Planning: Consistent coding enables engineers to accurately identify rehabilitation requirements and select appropriate intervention methods (Halfawy et al., 2008).

Asset Prioritization: Coding systems enable asset managers to prioritize rehabilitation interventions based on defect severity, optimizing limited resources.

Data Consistency: Standardized coding enables integration of condition assessment data with asset management systems, supporting long-term planning and trend analysis.

2.3 Quality Assurance in CIPP Rehabilitation

Quality assurance is critical in CIPP rehabilitation to ensure long-term performance of the installed liner. Key quality verification activities include pre-installation CCTV inspection, material verification, curing process monitoring, and post-installation inspection (ASTM F2019, 2009). Post-installation deflection measurement using profilometry equipment is essential to confirm that the liner has properly conformed to the host pipe geometry.

2.4 Research Gap

Existing research has extensively investigated sewer inspection methods, trenchless rehabilitation technologies, liner performance, and defect coding standards. Similarly, international standards provide comprehensive technical guidance for individual aspects of sewer rehabilitation. However, comparatively few publications describe how these engineering standards are integrated into a complete field implementation methodology applicable to large-scale municipal rehabilitation projects.

Most published studies focus on laboratory investigations, material characterization, or individual rehabilitation technologies, whereas practical coordination between inspection, engineering assessment, rehabilitation planning, quality assurance, and post-installation verification receives comparatively limited attention.

The present study addresses this gap by documenting a field-validated implementation framework developed through practical engineering experience. Rather than introducing new rehabilitation materials or technologies, the study demonstrates how existing international standards can be integrated into a repeatable engineering workflow that improves consistency and traceability throughout the rehabilitation lifecycle.

3. Methodology

3.1 Project Overview

The proposed implementation framework was developed from field experience obtained during multiple municipal gravity sewer rehabilitation projects completed over several years. Rather than representing a controlled experimental programme, the methodology documents standardized engineering procedures that were consistently applied during planning, inspection, rehabilitation, quality control, and project acceptance.

The framework integrates internationally recognized engineering standards with established construction practices to produce a repeatable workflow suitable for municipal gravity sewer rehabilitation programmes.

3.2 Condition Assessment and Defect Coding

The condition assessment workflow comprised three primary stages:

Stage 1: Pipeline Cleaning

1. Prior to CCTV inspection, all pipeline sections were cleaned using high-velocity water jetting equipment to remove debris, grease, roots, and other obstructions. Cleaning was performed to ensure clear visibility for subsequent CCTV inspection. The cleaning process involved:
2. Deployment of high-pressure water jetting equipment (typically operating at pressures between 1,500 and 3,000 psi)
3. Jet nozzle selection based on pipe diameter and debris type
4. Removal of accumulated sludge, sand, rocks, grease, and other solid or semi-solid materials

5. Disposal of all cleaning residuals at approved facilities
6. If cleaning of an entire section could not be successfully performed from one manhole, the equipment was repositioned to the other manhole and cleaning reattempted. In cases where successful cleaning could not be achieved due to major blockages, the rehabilitation approach was reassessed in consultation with the project consultant.

Stage 2: CCTV Inspection

Robotic CCTV inspection systems were deployed to conduct comprehensive visual assessment of pipeline condition. The inspection process recorded continuous video footage along the entire length of each pipeline section, capturing structural and operational defects.

The CCTV inspection process followed these key steps:

1. **Pre-Inspection Setup:** Calibration of the CCTV system, ensuring proper lighting and camera orientation for high-quality video capture
2. **Manhole Entry:** Controlled entry and retrieval of the CCTV crawler through the manhole, ensuring safe operation in confined spaces
3. **Full-Pipe Run:** The CCTV crawler traversed the full length of the pipeline section, capturing continuous video footage of the pipe interior
4. **Defect Identification:** Defects observed during the inspection were identified and logged using the software interface (e.g., IKAS Evolution)
5. **Data Recording:** All inspection data, including video footage, defect logs, and survey information, were systematically recorded and stored for analysis and reporting

Stage 3: Defect Coding and Reporting

Defects identified during CCTV inspection were classified and coded using the WRC Manual of Sewer Condition Classification (5th Edition) and EN 13508-2 standards (WRC, 2016; CEN, 2011). The coding process involved:

1. **Structural Defect Coding:** Identification of defects including cracks, fractures, collapses, and deformations. Each defect was assigned a grade (1-5) based on its severity and documented with its location (chainage), orientation, and dimensions (PUB, 2023).
2. **Operational Defect Coding:** Identification of defects including roots, deposits, obstructions, and infiltrations. Each defect was coded with its type, location, and severity grade (PUB, 2023).
3. **Quality Verification:** All coding was subject to internal quality checks to ensure accuracy and consistency, with random verification by independent reviewers.
4. **Reporting:** Comprehensive inspection reports were prepared, including CCTV video data, still images of key defects, survey records, and defect coding summaries. These reports served as the basis for rehabilitation planning and client/consultant approvals.

3.3 UV-CIPP Rehabilitation Workflow

The UV-CIPP rehabilitation methodology followed a systematic sequence of activities:

1. **Preliminary Works and Mobilization:** Work areas were cordoned off with safety barriers and signage. Permits to Work and NOCs were obtained from relevant authorities. All plant, equipment, and materials were mobilized to site. Toolbox talks were conducted to ensure all personnel understood the scope, methodology, and safety requirements.

2. **Sewer Isolation and Flow Control:** Where required, flow control measures were implemented using over pumping arrangements and mechanical stoppers. Isolation was coordinated to minimize service disruption.
3. **Final Cleaning and Pre-Installation Inspection:** Prior to liner insertion, pipeline sections received final cleaning verification. A pre-installation CCTV inspection was conducted to confirm that the pipeline was free of debris and obstructions that could compromise liner installation.
4. **Liner Insertion:** The UV-CIPP liner (resin-impregnated fiberglass material tube) was inserted into the pipeline section using a hydraulic winch system. Manual feeding from the insertion manhole was carefully controlled to prevent damage to the liner from manhole openings, ladders, or pipe edges. The liner's integrated anti-slip film and pre-liner provided protection against mechanical loads during insertion.
5. **End Can Installation and Light Train Insertion:** Metal end cans were installed at both ends of the liner to facilitate air inflation and connection to the UV light train. The UV light train (featuring UV lamps switchable in stages from 400 W to 600 W depending on diameter) was then inserted into the liner. The system includes integrated thermal-resistant cameras for real-time monitoring of the curing process (ASTM F1216, 2022).
6. **Inflation and Curing:** The liner was inflated using compressed air to ensure full contact with the host pipe. The UV light train was then activated, initiating the curing process through photoinitiated reaction (ASTM F1216, 2022). IR sensors monitored laminate temperature during curing, ensuring optimal curing conditions. The curing process was visually monitored using the integrated camera system.
7. **Post-Curing Activities:** Upon completion of the curing process, the UV light train was removed. End cans were detached, and excess cured liner at both ends was cut and prepared. The inner plastic foil was removed from the cured liner. Sealing materials were applied to seal circumferential ends between the CIPP liner and the existing pipe.
8. **Post-Installation Inspection and Verification**: A post-installation CCTV inspection was conducted to verify the quality of the rehabilitation work. Deflection measurements were performed using Pipeline Profiler software (ovality measurement) to confirm that the liner had properly conformed to the host pipe geometry.

3.4 Quality Assurance and Control

Quality assurance followed a structured Inspection and Test Plan (ITP) with defined hold points requiring consultant approval:

Hold Point 1: Material approval and verification prior to installation

Hold Point 2: Pre-installation CCTV inspection confirming pipeline readiness

Hold Point 3: Post-installation CCTV inspection and deflection measurement verification

All inspection records, including CCTV video data, survey reports, still images of defects before and after rehabilitation, and deflection measurement reports, were compiled and submitted for review and approval.

4. Results

The proposed implementation framework was successfully applied across multiple gravity sewer rehabilitation projects involving pipelines ranging from DN150 to DN2000. Throughout these projects, standardized inspection procedures, defect coding protocols, rehabilitation activities, and quality verification processes were consistently implemented using internationally recognized engineering standards.

The framework demonstrated that integrating condition assessment, standardized coding, rehabilitation execution, and quality assurance into a single workflow improved documentation consistency, facilitated engineering decision-making, and simplified consultant review and project acceptance.

Project statistics are summarized in Table 2.

Parameter	Value
Total sewer inspected	>120 km
Pipe diameter	DN150–DN2000
Structural & operational defects	>4,500
UV-CIPP installations	>280
Coding standard	WRC 5th Edition / EN13508-2
Post-installation CCTV	100%
Deflection verification	Pipeline Profiler

4.1 Engineering Observations

Several practical observations emerged during implementation**.**

First, pipeline cleaning quality directly influenced the effectiveness of CCTV inspection and rehabilitation planning. Insufficient cleaning frequently resulted in repeat inspections and additional maintenance activities before rehabilitation could proceed.

Second, standardized defect coding significantly improved communication between inspection teams, design engineers, contractors, and consultants by providing consistent terminology and objective descriptions of observed defects.

Third, post-installation CCTV verification combined with ovality measurements using Pipeline Profiler provided effective confirmation that rehabilitation objectives had been achieved prior to project acceptance.

4.2 UV-CIPP Rehabilitation Outcomes

UV-CIPP liners installed: 280+ across DN150-DN600

Post-installation verification: Zero quality failures recorded across all installations

4.3 Quality Verification Outcomes

Post-installation CCTV inspection confirmed that all installed liners met the specified quality requirements. Deflection measurements using Pipeline Profiler software confirmed proper liner conformance to host pipe geometry. The post-installation sealing of circumferential ends was verified, ensuring watertight performance.

5. Discussion

5.1 Benefits of the Integrated Methodology

The integrated methodology combining systematic condition assessment, standardized defect coding, and UV-CIPP rehabilitation offers several key benefits:

1. Optimized Rehabilitation Planning: Accurate defect coding enables precise identification of rehabilitation needs, ensuring that interventions are targeted to the specific defects present in each pipeline section. This reduces the risk of over- or under-rehabilitation, optimizing asset management resources.

2. Standardized Communication: The use of internationally recognized standards (WRC and EN 13508-2) enables consistent communication of pipeline condition among project stakeholders, including clients, consultants, and contractors. This standardization facilitates collaboration and reduces the risk of misinterpretation.

3. Quality Assurance Throughout the Process: The structured workflow, including pre-installation and post-installation inspections, ensures that quality is verified at each stage of the process, minimizing the risk of installation failures.

4. Improved Asset Management: The documentation generated through the process, including condition assessment reports and rehabilitation records, provides valuable input for long-term asset management and future planning.

5.2 Practical Challenges and Lessons Learned

Based on field experience, several practical challenges were encountered:

1. Sewer Isolation and Flow Control: Effective isolation of sewer sections during rehabilitation was essential to maintain service continuity. Careful planning and coordination were required to implement flow control measures without causing backflow or surcharging.

2. Pipeline Cleaning: Thorough cleaning was critical for successful CIPP installation. In some cases, multiple cleaning passes were required to achieve the necessary cleanliness for proper liner adhesion and installation.

3. Quality Verification: The post-installation CCTV inspection and deflection measurement were essential for confirming installation quality. In some cases, additional sealing was required to ensure watertightness at liner ends.

4. Operational Procedures: Strict adherence to established method statements and safety procedures was essential for personnel safety, with particular emphasis on confined space entry procedures and HSE compliance.

5.3 Future Directions: AI-Assisted Inspection

While this paper focuses on established methodologies, it is worth noting the potential of emerging technologies, such as AI-assisted pipeline inspection platforms, to further optimize the defect coding and reporting process. These technologies are being developed to reduce manual inspection time, improve consistency in defect identification, and enable near-real-time reporting.

AECOM has developed Sewer Logic as an AI/ML-driven tool to automatically identify and code defects, recommend rehabilitation strategies, and improve capital improvement plan development (Building Transformations, 2022). Sewer Logic uses AI and vision detection for validation to assess accuracy of coding, detection of uncoded pipe or missed codes, and recommending pipe rehabilitation and operational treatments (Building Transformations, 2022). The system has been trained on 93,000 images with over 500,000 labelled defects and is trained on over 110 individual NASSCO PACP modifiers representing 95% of the PACP defects typically seen on infrastructure rehabilitation programs (Building Transformations, 2022).

The use of Artificial Intelligence and Machine Learning technology is increasingly recognized as a disruptor in the sewer assessment industry, with organizations focused on improving methods and workflows to enhance the speed and accuracy of the sewer assessment process (Building Transformations, 2022). However, as noted by NASSCO, there is presently no ADR software system certified by NASSCO that has been verified as recognizing every code combination in the Pipeline Assessment Certification Program (PACP) format, and there are no industry-published metrics regarding the types of observations that are consistently identified with ADR (NASSCO, 2024). The industry is currently delivering ADR as an "assisted" solution method with certified individuals confirming and augmenting ADR evaluations, and NASSCO has published Guidelines for Quality Control of NASSCO's PACP, LACP and MACP Surveys providing recommendations for quantifying the acceptability of inspections, including quality validation of ADR solutions (NASSCO, 2024).

Recent academic research has explored the application of deep learning models for defect detection in infrastructure. Huang et al. (2025) proposed a method for automatic crack defect detection via multiscale feature aggregation and adaptive fusion, published in *Automation in Construction*. Inbar et al. (2023) analyzed secondary wastewater-treatment processes using Faster R-CNN and YOLOv5 object detection algorithms, published in the *Journal of Cleaner Production*. These studies demonstrate the growing interest in applying computer vision and machine learning techniques to infrastructure assessment.

The manual coding approach described in this paper remains the industry standard for ensuring accuracy and quality, particularly for critical infrastructure projects, while AI continues to mature as a complementary tool for enhancing efficiency and consistency. As NASSCO has indicated, "better quality video and more diverse imagery datasets will improve machine learning capability to consistently code a broader range of defects in more diverse ranges of pipe materials" (NASSCO, 2024).

5.4 Study Limitations

Several limitations should be acknowledged.

First, this study documents practical engineering implementation rather than controlled experimental testing. Consequently, direct comparisons between UV-CIPP and alternative rehabilitation technologies were outside the scope of this work.

Second, detailed project records remain confidential under contractual agreements with project owners. Therefore, only aggregated project statistics are presented within this paper.

Finally, long-term structural performance beyond project completion was not evaluated. Future studies should investigate long-term monitoring, life-cycle cost assessment, and comparative performance of different rehabilitation techniques.

6. Conclusion

This paper presented a practical implementation framework for gravity sewer rehabilitation that integrates standardized condition assessment, defect coding, rehabilitation planning, UV-CIPP installation, quality assurance, and post-installation verification into a unified engineering methodology. The framework was developed through extensive field implementation across multiple municipal rehabilitation projects involving more than 120 km of inspected sewer pipelines.

The key findings are:

1. **Systematic condition assessment is essential** for identifying and prioritizing rehabilitation needs, enabling targeted interventions that optimize asset management outcomes.

2. **Standardized defect coding** using internationally recognized standards (WRC and EN 13508-2) enables consistent communication, accurate rehabilitation planning, and integration with asset management systems.

3. **UV-CIPP technology**, when implemented with proper quality assurance, provides a reliable and efficient solution for gravity sewer rehabilitation, with zero quality failures recorded across all installations.

4. **Post-installation inspection and deflection measurement** are critical for verifying installation quality and ensuring long-term performance of the rehabilitated pipeline.

5. **Practical challenges**, including sewer isolation, pipeline cleaning, and confined space safety, require careful planning and adherence to established procedures.

Although the individual engineering standards discussed in this paper are well established, their coordinated application throughout the rehabilitation process has received comparatively limited attention in published engineering literature. The implementation framework presented here demonstrates one practical approach for integrating these standards into municipal rehabilitation programmes.

Future research should investigate long-term performance monitoring, digital asset management integration, AI-assisted defect recognition, and quantitative evaluation of workflow efficiency across different rehabilitation programmes.

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Conflict of Interest

The author declares that there are no financial or personal conflicts of interest that could have influenced the work presented in this paper.

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