REVIEW AND ANALYSIS OF POST INSTALLATION PIPE DEFECTS

H. Al-Saleem (Independent Contractor/ ProjectMax), S. Apeldoorn (ProjectMax), Branko Veljanovski (Auckland Council)

ABSTRACT

Closed-Circuit Television (CCTV) inspection is mandated by all Territorial Authorities in New Zealand as a quality assurance tool/practice to evaluate the construction quality of stormwater concrete pipes. However, the assessment and acceptance processes have varied among different authorities due to the lack of a clear and unified assessment methodology or acceptance criteria.

Since 2017, the authors have developed a structured assessment methodology where the impact of each observed defect is evaluated against the following parameters:

- **Structural stability**
- **Durability**
- **Water and silt tightness**
- **Hydraulic capacity**

The criteria for the assessment of CCTV inspections are prioritized as follows:

a) **Project Specifications**: Any limitations or special requirements included in or assessed to be part of the project specifications.
b) **TA's Code of Practice**: Design and construction specifications as outlined in the TA's Code of Practice.
c) **Concrete Pipes Manufacturing Standard**: Compliance with the AS/NZS 4058:2007 standard for concrete pipes manufacturing.
d) **Manufacturer's Recommended Practice:** Adherence to the recommended practices of New Zealand concrete pipes manufacturers, as covered by CPAA publications.
e) **Research and Published Information**: Consideration of relevant New Zealand and international research work and published information.

With the release of the 4th Edition of Water New Zealand's "New Zealand Gravity Pipe Inspection Manual" at the end of 2019, the authors contributed a new section (E3), introducing an industry aligned framework for assessing newly installed pipelines for quality assurance.

This section provides a much-needed standardized basis for defect evaluation and acceptance.

CCTV inspection footage from more than 220 projects, ranging from single pipelines for small developments to hundreds of pipelines for surface drainage networks of major expressway projects, was assessed using the above methodology and criteria.

This paper presents an analysis of the data collected during the assessment of these projects, indicating that most observed defects are either within the limits of acceptable pipe pre-installation defects, self-healing cracks, within the serviceability limits of the pipes and pipeline design, or assessed to have no effect on the future safe performance of the pipelines.

Some observed defects were assessed as having an unclear effect on one or more of the four assessed performance parameters. To clarify the long-term effect, monitoring of the defect was advised following a strict monitoring methodology developed by the authors, which will be presented in the paper.

A very low percentage of the observed defects were found to be non-compliant with one or more of the performance parameters, necessitating repair or, in rare severe cases, full replacement.

The paper also includes a statistical analysis of the observed defects, along with conclusions and recommendations that are expected to benefit the industry and serve as a basis for further improvement of both construction techniques and future development of specifications.

1. CCTV INSPECTION DATA

1.1 INTRODUCTION

This study analyses CCTV footage collected from inspections of newly installed stormwater networks and culverts in New Zealand. The data, obtained since early 2019, was provided to the authors for an independent assessment of observed defects.

While the dataset does not encompass every installation nationwide, it is believed to be statistically representative of the defect patterns within newly installed concrete stormwater pipes. This analysis aims to provide insights into the prevalence and nature of these defects, contributing to a better understanding of infrastructure quality.

The standard information provided for assessment typically includes the raw CCTV footage and the associated CCTV inspection report. However, to facilitate a more comprehensive understanding of potential defect sources and their long-term implications, supplementary data was often supplied. This additional information varied, but commonly included design plans, detailed records of installation methods, and photographic documentation of the installation process.

Furthermore, contributing factors such as the properties of bedding materials, the impact of construction traffic, and the surrounding soil properties were sometimes included. These contextual elements are crucial for accurately diagnosing the root causes of observed defects and predicting their potential future effects on the stormwater infrastructure's performance and longevity. By including this additional information, the analysis can provide a much more in depth look into the causes of the defects.

1.2 STAKEHOLDER REQUESTS FOR INDEPENDENT DEFECT ASSESSMENTS

Independent assessments of stormwater infrastructure defects are typically requested by key stakeholders, including contractors, pipe suppliers, engineers, and asset owners. These requests generally fall into one of the following categories:

- **Comprehensive Project Review:** Stakeholders may provide all CCTV footage and inspection reports for an entire project, requesting a complete assessment to identify and document all defective pipelines.
- **Targeted Pipeline Evaluation:** Engineers or asset owners may submit specific CCTV footage of pipelines they have identified as potentially problematic, seeking an independent evaluation of these particular sections.
- **Material vs. Installation Defect Determination:** Pipe suppliers often request assessments of specific pipeline footage to determine whether observed defects are attributable to material deficiencies or installation errors.
- **Repair Method Consultation:** Stakeholders may submit CCTV footage of known defective pipelines, seeking expert advice on appropriate repair methodologies.

1.3 GEOGRAPHICAL DISTRIBUTION OF ASSESSED PIPELINES

Figure 1: Number of Assessed Pipelines per Region

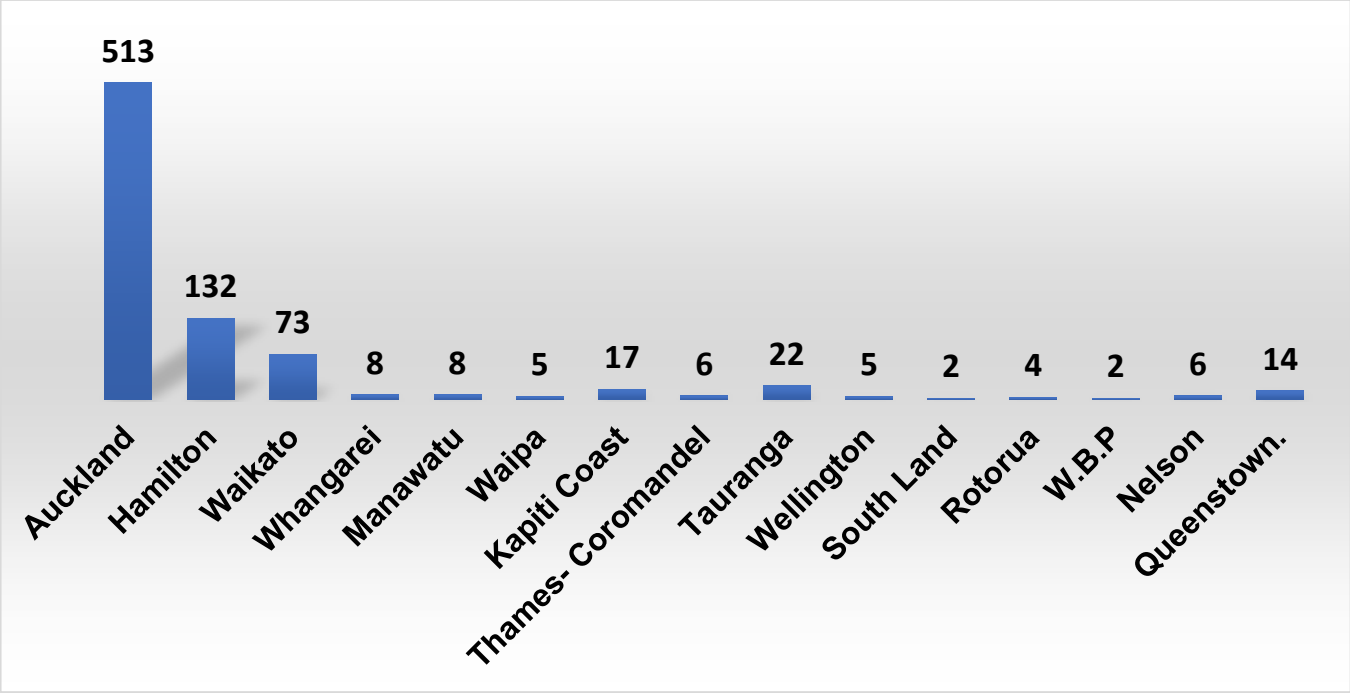


Figure 1 illustrates the regional distribution of pipelines included in this analysis. As anticipated, the majority of data originates from the Auckland region, reflecting the high concentration of construction activity in this area.

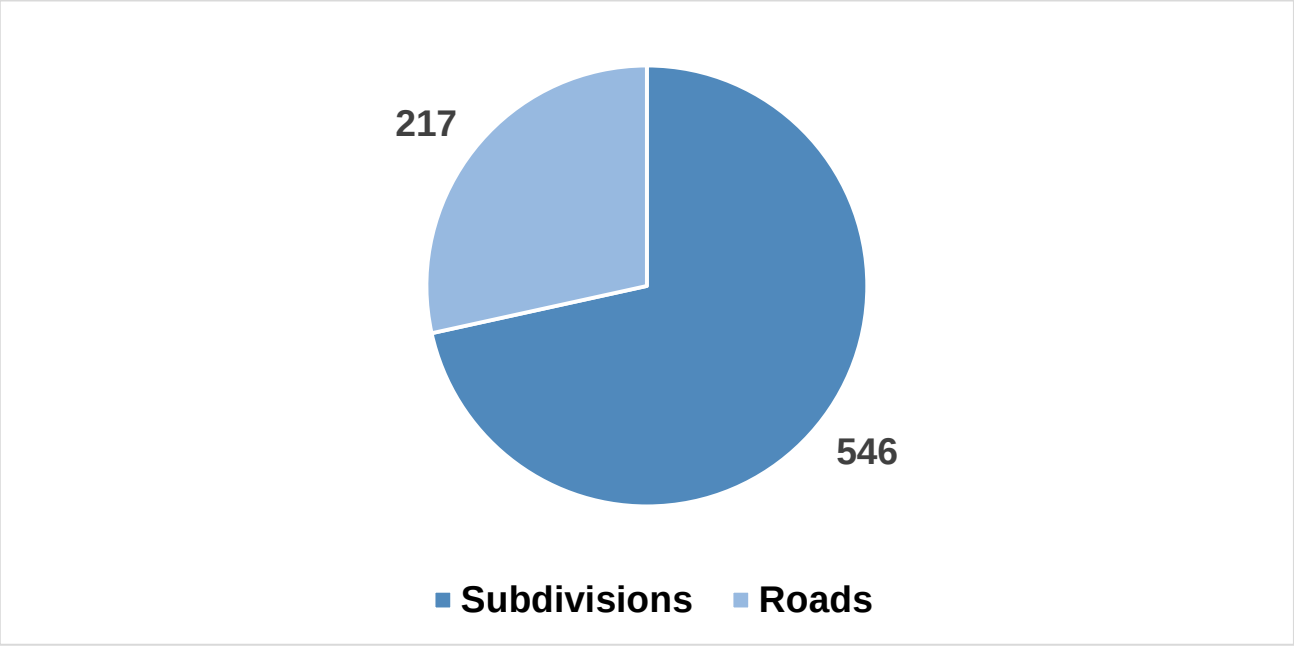
Hamilton represents the second-largest data source, primarily due to the inclusion of extensive data from the Waikato Expressway - Hamilton Section project. Similarly, the Waikato region's data is largely derived from other sections of the Waikato Expressway and developments located near the Auckland regional boundary.

1.4 DISTRIBUTION OF ASSESSED PIPELINES BY INSTALLATION TYPE

Figure 2 presents the breakdown of assessed pipelines according to the type of installation project. Road projects account for approximately 28% of the data sources, while subdivision development projects constitute the remaining 72%.

It's important to note that pipelines within subdivision projects encompass more than just residential drainage. They include the entire stormwater network within the subdivision, covering roads, car parks, reserves, service areas, and house drainage systems.

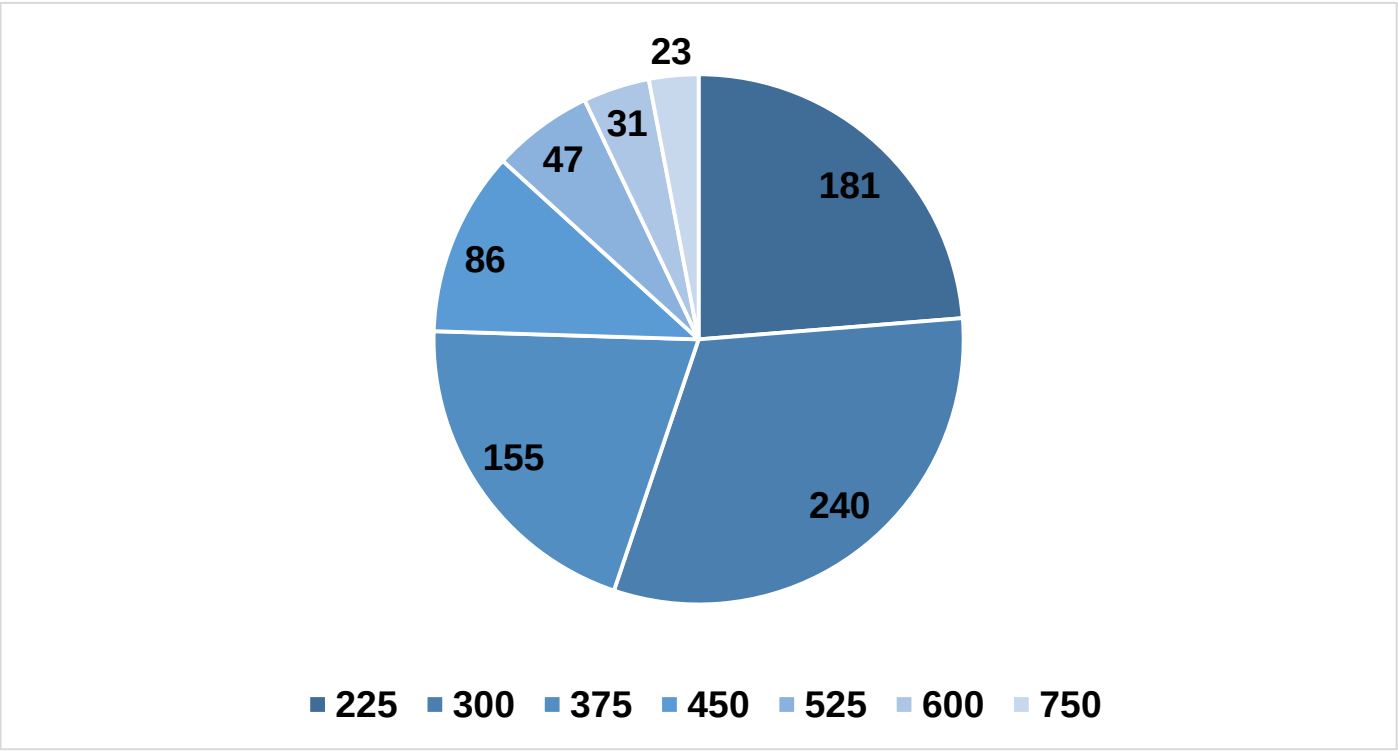
Figure 2: Distribution of Assessed Pipelines by Installation Type



1.5 ASSESSED PIPELINE SIZES

Figure 3 illustrates the distribution of pipeline sizes assessed in this work. While precise nationwide data on the quantity of each pipe size is unavailable, our experience suggests that the observed distribution closely aligns with the typical distribution in New Zealand. Notably, 300mm nominal diameter pipes represent the highest percentage, followed by 225mm, with a subsequent decline in the number of pipelines observed for larger sizes. During the last five years of assessment and data collection, only a few pipelines larger than 750mm in diameter were encountered. These were excluded from the analysis because their defects were primarily attributed to manufacturing features, improper handling, or installation errors, and their assessment often involved direct entry and inspection.

Figure 3: Number of Assessed Pipelines per Nominal Diameter



2. ASSESSMENT METHODOLOGY

The CCTV inspection assessment methodology used in this study evaluates the impact of each observed defect against four key parameters: structural stability, durability, water and silt tightness, and hydraulic capacity.

To ensure consistency and objectivity in defect evaluation, the following 'hierarchy' of assessment criteria was adopted:

a) Project Specifications: Any limitations or specific requirements outlined within the project specifications.

b) Codes of Practice and Design Standards: Including those issued by Waka Kotahi NZ Transport Agency and local authorities.

c) Concrete Pipe Manufacturing Standards: Compliance with AS/NZS 4058:2007 for reinforced concrete pipe manufacturing.

d) Manufacturer's Recommended Practices: Adherence to recommended practices from New Zealand concrete pipe manufacturers, as documented in CPAA publications.

e) Research and Published Information: Consideration of relevant New Zealand and international research and published data.

In late 2019, the 4th edition of Water New Zealand's "New Zealand Gravity Pipe Inspection Manual (NZGPIM)" was released, featuring a new section (E3) contributed by the authors.

This addition established a standardised framework for defect evaluation and acceptance across the industry.

Given that the majority of the data originated from Auckland projects, the Auckland Council Healthy Waters criteria was applied for criterion (b) and were applied to projects in other regions where no specific local criteria existed.Key assessment criteria derived from the Auckland Council Code of Practice for Land Development and Subdivision – Stormwater included:

- Clause 4.3.9.1 – c: Minimization of infiltration and exfiltration within the stormwater network.
- Clause 4.3.9.4: Conformity of concrete pipes to AS/NZS 4058:2007.
- Clause 4.3.18: CCTV inspections conducted according to the New Zealand Gravity Pipes Inspection Manual (NZGPIM).

Each observed defect was then categorized as per the above criteria and the NZGPIM guidelines into one of the following categories:

- **Acceptable defect/no defect (Green Celes in the results Tables);**
- **Unacceptable defect requiring repair or replacement (Red Celes in the results Tables);** or
- **Defect requiring monitoring and/or the Engineer or Contractor decision for repair or replacement (Yellow Celes in the results Tables)**.

3. RESULTS AND ANALYSIS

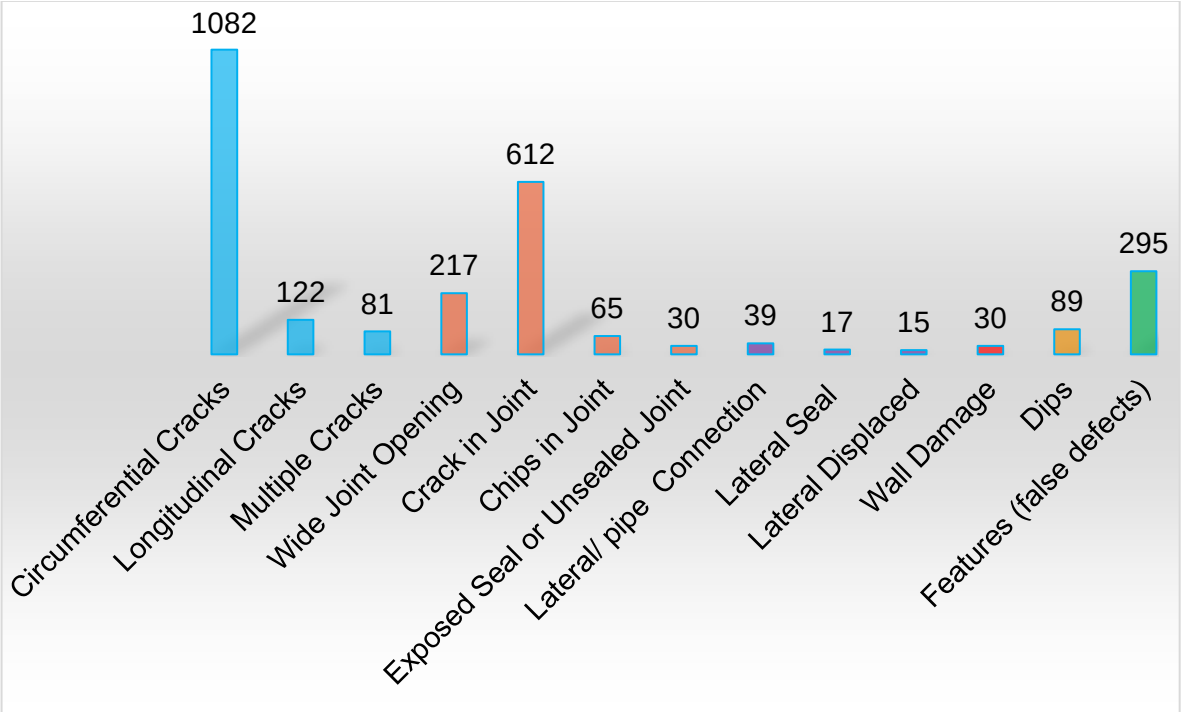
Figure 4 illustrates the distribution / total number of defect types observed across the assessed pipelines.

The general trend of results indicates that the major defect types observed are circumferential cracks, cracks in the joint area, other joint defects, and various additional crack types. Notably, there are a substantial number of features, initially 'flagged' as defects by asset owners, that were re-classified as *false defects* following independent review, as shown in Figure 4.

To analyse these results, the observed defects are grouped as follows::

a) Cracks
b) Defects of pipe joints
c) Lateral defects
d) Pipe wall defects
e) Dips
f) False defects

Figure 4: Number of Defects per Type Observed in the Assessed Pipelines



3.1 CRACKS IN PIPE WALL

Table 1 presents all crack types observed in the pipe walls of the assessed pipelines. As anticipated, circumferential cracks represent the most common type of crack in concrete pipes, followed by longitudinal cracks and, to a lesser extent, multiple intersecting cracks.

The concrete pipe industry typically specifies acceptance limits for cracks in pipe walls, based on crack width, which is measured according to established procedures (AS/NZS 2007, McGuire & Harrison 2012). Specifically, AS/NZS 4058:2007, Clause C4.3, defines crack width as the width measured at a depth exceeding 3mm, with consecutive measurements taken at 30mm intervals over a minimum length of 300mm. However, applying this standard method to installed small-diameter pipes is often physically impractical. Furthermore, interpreting crack width solely from CCTV imagery without forensic verification can be misleading. The apparent crack width in CCTV images is influenced by factors such as:

a) Camera-to-crack distance
b) Camera angle
c) Camera resolution, and
d) Lens type (e.g., wide-angle).

Consequently, accurate crack width assessment in these situations often necessitates a general evaluation of the crack's condition, informed by assessor experience. Key considerations in this evaluation include:

a) Crack length and location
b) The stage of the healing process
c) Any evidence of present or past infiltration, and

d) The condition and shape of the crack edges

Furthermore, the New Zealand Gravity Pipes Inspection Manual, Appendix C, provides guidelines that can be used to assess pipe crack widths from CCTV footage.(Water NZ 2019)

3.1.1 CIRCUMFERENTIAL CRACKS

Circumferential cracks were by far the most common of all cracks observed. These type of cracks were more frequently observed in smaller diameter pipes (225, 300, and 375mm), while larger diameter pipes, due to their higher moment of inertia and thicker walls, exhibited fewer such cracks, consistent with the findings of Al Saleem and Langdon (Al Saleem and Langdon 2014)

The assessment indicates that most circumferential cracks were within acceptable criteria, being narrow, self-healed, in the process of healing, or expected to remain stable throughout the pipeline's design life.

Infiltration from circumferential cracks was rare. However, a small percentage of cracks with excessive infiltration were assessed as requiring repair or replacement.

A smaller percentage of circumferential cracks, characterized by width, displacement, or evidence or potential for significant infiltration, were designated for monitoring or repair, as deemed feasible or required by the engineer.

Table: 1 Number of Cracks observed in the Assessed Pipelines

Diameter ND mm	No. of lines	Circumferential Cracks			Longitudinal Cracks			Multiple Cracks		
225	**181**	283	2	2	4		1	3		
300	**240**	368	7	21	8	1		6	2	
375	**155**	284	5	12	62			40	1	4
450	**86**	44	10	4	21	2		4	3	2
525	**47**	33		1	3	1		2	1	
600	**31**	3		3	9			3	10	
750	**23**				10					
Number of Defects/ As Assessed		1015	24	43	117	4	1	58	17	6
Percent Defects/ As Assessed		94%	2%	4%	96%	3%	1%	72%	21%	7%
Total	763	1082			122			81		

3.1.2 LONGITUDINAL CRACKS

Reinforced concrete pipes are designed to develop longitudinal cracks under load, activating the steel reinforcement as intended (Al Saleem and Langdon 2014), i.e. A longitudinal crack is a normal response to working loads applied

However, assessment data from 763 inspected lines revealed only 122 longitudinal cracks. Accounting for lines with more than one crack, this indicates that less than 10% of the inspected lines exhibited the designed cracking behaviour, suggesting that approximately 90% might be overdesigned. This lack of longitudinal cracking could be attributed to one or more factors:

a) Selection of a higher-than-required pipe class
b) Overestimation of live and dead loads
c) Underestimation of the pipe bedding factor due to high-quality bedding materials, excessive material quantity, or over-compaction, and
d) A high design safety factor in pipe manufacturing.

Given the high incidence of circumferential cracks observed in the same pipelines, it is likely that factor (c) plays a significant role. High compaction increases the bedding factor, thereby reducing longitudinal cracking while simultaneously increasing the potential for circumferential cracks.

Furthermore, the assessment showed that 96% of the pipes with longitudinal cracks were within acceptable design limits, 1% exhibited cracks exceeding these limits (resulting in infiltration, slabbing, or displacement and requiring structural repair or replacement), and 3% were recommended for monitoring to ensure long-term structural integrity before acceptance (refer Table 1 Longitudinal Cracking column).

3.1.3 MULTIPLE CRACKS

Ideally, properly manufactured and installed reinforced concrete pipes should not exhibit multiple cracks. However, a number of assessments from CCTV inspections indicate their presence. Upon review of the original data sources, it was found that many of these assessments, identified as multiple cracks, were actually multiple short longitudinal cracks near joints or hairline cracking in the pipe wall due to surface layer shrinkage.

It is crucial to note that genuine multiple cracks signify a serious issue. These cracks typically occur when a pipe experiences significant stress during handling and/or installation. Therefore, when true multiple cracks are observed, careful assessment is essential.

Despite potential misinterpretations, the data in Table 1 reveals that 28% of the observed cracks required either repair or replacement, or further monitoring, where possible. This monitoring is necessary to ensure that the internal cracks are not indicative of extensive external damage.

3.2 DEFECTS OF PIPES JOINTS

Table 2 details the defects observed in pipe joints and their surrounding areas within the assessed pipelines. As previously discussed regarding crack assessment, accurate measurement of joint opening widths from CCTV footage of small-diameter pipes is

challenging. Therefore, assessors must estimate joint opening widths, comparing these estimations to both the manufacturer's recommended typical width and the safe width derived from the joint design specifications.

Concrete pipe standards define acceptable dimensional limits for chips and cracks in the installed pipe's joint area. These minor defects are expected to occur due to joint design or handling during manufacturing. During CCTV footage assessment, it is critical to accurately estimate these defects and compare them to the established limits, acknowledging the inherent limitations of CCTV imagery.

Table: 2 Number of Joint Defects Observed in the Assessed Pipelines

Diameter ND mm	No. of lines	Wide Joint Opening			Crack in Joint			Chips in Joint			Exposed Seal or Unsealed Joint		
225	181	37		1	67		3	8					2
300	240	67	2	2	123		5	17	1	3			5
375	155	38		2	163			12		1			3
450	86	34		1	90			4				1	16
525	47	31			61			18					1
600	31	2			49								
750	23				48		3	1					2
Number of Defects/ As Assessed		209	2	6	601		11	60	1	4		1	29
Percent Defects/ As Assessed		96%	1%	3%	98%	0%	2%	92%	2%	6%	0%	3%	97%
Total	763	217			612			65			30		

Assessors may recommend accepting defects that slightly exceed these limits if they determine that the defects will not have long-term adverse effects on the pipeline. This decision can prevent the complex and costly process of pipeline replacement or joint repair.

3.2.1 WIDE JOINT OPENING

The majority of observed wide joint openings presented in Table 2 were assessed as being due to pipe installation at a slight angle, causing the joint to appear wide on one side and narrow on the other.

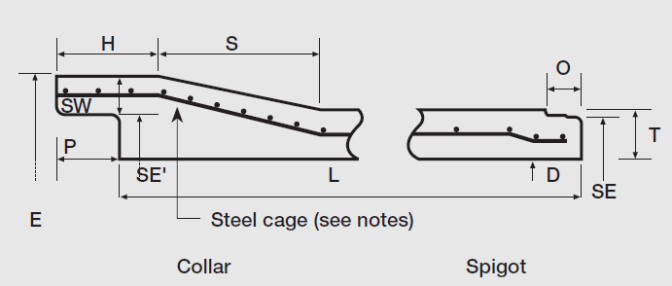
Analysis of the joint designs of concrete pipe produced in New Zealand indicates that the joints are designed with a generous interlocking distance. This allows the joint to be deflected at a slight angle without compromising watertightness. This design also allows the pipes to pop up slightly after installation, increasing the opening width without adverse effects.

Based on this analysis, 96% of the wide joint openings were assessed as acceptable. The remaining 3%, with signs of leakage or potential leakage, were assessed as requiring repair or further monitoring.

3.2.2 CRACKS IN JOINT AREA

Rubber Ring Joint (RRJ) reinforced concrete pipes are typically designed with the joint configuration shown in Figure 5. Due to this configuration, the reinforcement cover at the collar side is significantly higher than the standard 10-25mm for other parts of the pipe barrel. Consequently, the collar side of the joint behaves like a plain concrete section, where cracking resistance comes from the concrete's inherently low tensile strength. Furthermore, normal concrete shrinkage may induce shrinkage cracks in the collar side due to the lack of reinforcement near the surface.

Figure 5: Typical RRJ Pipes Joint Detail



These factors often result in the observation of short hairline cracks in the joint area, especially when high-resolution cameras are used and panned across the pipe joints, or when pipelines are inspected with damp surfaces, which exaggerate the crack's width and shape. Experienced CCTV inspectors typically ignore these cracks as normal features or note them as comments in their reports. However, during the assessment of pipelines included in this work, these features were highlighted as defects by some inspectors but were more often identified during the Asset Owners' review of the inspection. An example of this type of defects is shown in Photograph 1.

Photograph 1: Crack in Joint Area

As anticipated, most of these defects were assessed as acceptable. Only a small percentage (2%) were assessed for replacement or repair, primarily those involving serious cracks in pipe collars that breached the joint's watertightness during installation.

3.2.3 CHIPS IN JOINT AREA

Concrete pipes are susceptible to chipping of the sharp concrete edges at the joints during handling and installation. Chips of specific dimensions are permitted in pre-installed pipes as part of the manufacturing tolerance.

An assessment of chips observed in the inspected pipelines revealed that 92% were within acceptable pre-installation dimensions or were estimated to have dimensions that do not compromise the joint's watertightness or the pipe's structural reinforcement. Only two pipelines exhibited chips requiring further monitoring to evaluate their long-term impact on joint watertightness. Conversely, 6% of the pipe joints were assessed to have sustained substantial concrete loss, resulting in either exposed structural reinforcement or compromised watertightness.

3.2.4 EXPOSED SEAL OR UNSEALED JOINTS

The specification of RRJ pipes mandates watertight stormwater pipelines. Therefore, joints with exposed or missing rubber seals are deemed non-watertight, regardless of observed infiltration during CCTV inspection.

Consequently, most pipelines with these defects were assessed as requiring replacement or repair to restore the specified watertightness. Only two pipelines were recommended for monitoring of their long-term watertightness due to unclear joint conditions observed during inspection.

3.3 LATERAL PIPE CONNECTION DEFECTS

3.3.1 ` LATERAL/ PIPE CONNECTION

Lateral connection defects are primarily attributed to workmanship quality rather than pipe or material quality. Common issues observed included improper use of vitrified clay saddles, incorrect pipe opening cuts, and inadequate epoxy mortar sealing. 74% of these defects were classified as minor, likely due to external sealing not visible during CCTV inspection and are not expected to cause significant infiltration. Repair or monitoring was recommended for the remaining defects (refer Table 3).

3.3.2 LATERAL SEAL

Specifications mandate sealed connections between vitrified clay saddles and PVC pipes to prevent excessive infiltration. However, 8 installations exhibited missing, improperly applied, or potentially compromised seals. An additional 11 installations (10 within a single project) showed minor seal defects deemed to have no long-term impact on pipeline watertightness. (refer Table 3).

3.3.3 LATERAL DISPLACED

The design of PVC lateral pipe connections to vitrified clay saddles allows for considerable deflection without compromising seal integrity. CCTV inspections from inside the pipe can exaggerate deflection angles, sometimes leading to misinterpretations of severe displacement. However, none of the observed displacements exceeded safe deflection limits or required repair or replacement.

Table: 3 Number of Lateral Defects Observed in the Assessed Pipelines

Diameter ND mm	No. of lines	Lateral/ pipe Connection			Lateral Seal			Lateral Displace		
225	181	6	1				1	2		
300	240	8	2	2			2	7		
375	155	6		3	11	1	2	6		
450	86	5								
525	47	1		2						
600	31	2								
750	23	1								
Number of Defects/		29	3	7	11	1	5	15		
Percent Defects/ As Assessed		74%	8%	18%	65%	6%	29%	100%	0%	0%
Total	763	39			17			15		

3.4 PIPE WALL DAMAGE

Pipe wall damage typically occurs when pipes are struck by external objects during installation, most likely during backfilling. While such damage is often severe, necessitating repair or replacement, minor damage attributed to manufacturing imperfections was also observed in the assessed pipelines.

Installation-related damage is generally characterized by wall perforations, spalling that exposes the main reinforcement, and frequently, significant infiltration or pressurized water flow. Conversely, minor damage typically manifests as cold joint casting issues, localized honeycombing, or damp areas indicating potential weep holes.

Table 4: Number of Wall Damage Observed in the Assessed Pipelines

Diameter ND mm	No. of lines	Wall Damage		
225	181			1
300	240	1		
375	155	1	1	2
450	86	3		9
525	47	1		
600	31	9		
750	23	1	1	
Number of Defects/ As Assessed		16	2	12
Percent Defects/ As Assessed		53%	7%	40%
Total	763	30		

Table 4 presents the frequency of wall damage observed in the assessed pipelines and their corresponding assessments. The results indicate that approximately half of the observed defects are severe, requiring repair or monitoring, while the remaining half are minor and deemed acceptable.

3.5 PIPE DIPS (STATIC WATER IN PIPE INVERT)

Stormwater pipelines and culverts are designed with a positive grade to ensure free water flow and prevent sediment accumulation, which can reduce hydraulic capacity and cause blockages.

However, dips, or negative grades, can occur due to several factors. These include:

- Improper bedding or subgrade preparation, leading to pipe end movement and vertical angles at joints.
- Incorrect level matching when connecting to existing manholes, forcing the last pipe section to be installed at a negative grade.
- Differential settlement of the pipe/manhole system, particularly in shallow grade pipelines

Table 5 presents the observed pipe dips. During the assessment, dip depths were measured from still images at defective pipeline joints, and their potential long-term effects on hydraulic capacity were evaluated. The assessment revealed that 98% of observed dips were less than 10% of the pipe diameter. These are generally considered to have a minor impact on hydraulic capacity. Furthermore, many of these minor dips were located at manhole ends, where accumulated sediments are likely to be cleared during heavy storms or routine manhole maintenance.

Table 4: Number of Dips Observed in the Assessed Pipelines

Diameter ND mm	No. of lines	Dips		
225	181	13		
300	240	25		
375	155	18	2	
450	86	10		
525	47	12		
600	31	6		
750	23	3		
Number of Defects/ As Assessed		87	2	
Percent Defects/ As Assessed		98%	2%	0%
Total	763	89		

The remaining 2% of dips, exceeding 10% of the pipe diameter, were referred to the design engineer for a detailed hydraulic capacity assessment. The engineer will determine if repair or replacement is necessary.

3.6 FALSE DEFECTS

Concrete pipe interiors often exhibit surface irregularities, including pores, which can lead to staining from contaminated water and susceptibility to mechanical erosion and scratching. Handling and installation processes, particularly on construction sites, contribute to these irregularities. Forklift operations, exposure to rainwater accumulation and drying, and open-ended installation conditions can all leave lasting marks on the pipe's internal surfaces.

During CCTV inspections, these marks can be misinterpreted as defects. Experienced CCTV operators typically recognize these as non-structural imperfections. However, some operators may investigate them further, and a minority may erroneously classify them as cracks or surface defects. Notably, QA Engineers and consultants reviewing the CCTV footages on behalf of the asset owners were the primary source of false defect identification.

Photograph 2 illustrates an example of such a false defect. Staining lines caused by contaminated water were incorrectly identified as longitudinal cracks. Closer inspection revealed no actual cracking, and the lines' location and shape were inconsistent with typical longitudinal crack characteristics.

Photograph 2: Staining of Pipe Wall Identified as Longitudinal Cracks

4. CONCLUSIONS

1. Methodology Standardization is Crucial:

- The study highlights the need for a standardized assessment methodology and acceptance criteria for CCTV inspections, as evidenced by the varying practices among different authorities.
- The authors' development of a methodology based on structural stability, durability, water/silt tightness, and hydraulic capacity, and its inclusion in the NZGPIM, providesan industry aligned framework for assessing newly installed pipelines for quality assurance.
- The prioritization of assessment criteria (project specifications, codes of practice, manufacturing standards, etc.) provides a robust framework.

2. Prevalence and Nature of Defects:

- The majority of observed defects are classified as acceptable, including pre-installation defects, self-healing cracks, and those within serviceability limits.
- Circumferential cracks are the most common crack type, particularly in smaller diameter pipes – however, it shall be noted that circumferential cracks do not affect the load carrying capacity of the pipe
- Longitudinal cracks are less frequent than expected, suggesting potential overdesign of pipes or conservative load estimations.
- A significant number of "false defects" are identified, highlighting the importance of experienced assessors and accurate interpretation of CCTV footage.
- Joint defects, and lateral connection defects are common.
- Dips are also relatively common, but most are considered minor.

3. Importance of Contextual Data:

- Supplementary data, such as, but not limited to the design plans, installation records, soil properties, are essential for accurate defect assessment and root cause analysis.
- The limitations of relying solely on CCTV images for accurate measurements (e.g., crack width/depth, joint opening) are emphasized.

4. Impact of Installation Practices:

- Many defects, particularly lateral connection issues and wall damage, are attributed to workmanship and installation quality.
- Improper bedding and subgrade preparation are identified as causes of dips.
- The handling of the pipes during the installation process contributes to defects such as chips in the joints, and wall damage.
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5. **Monitoring and Repair Strategies:**
    - A monitoring methodology is developed for defects with unclear long-term effects.
    - Repair or replacement is recommended for a small percentage of defects that significantly compromise performance parameters.
    - The paper shows that most defects are minor, and do not require repair.
6. **Statistical Analysis and Regional Distribution:**
    - The study provides valuable statistical data on the frequency and types of defects observed in various pipeline sizes and installation types.
    - The regional distribution of assessed pipelines reflects construction activity, with Auckland having the highest concentration.
    - The subdivision development projects account for the majority of the assessed pipelines.
7. **Industry Implications:**
    - The findings and recommendations of this study are expected to benefit the stormwater infrastructure industry by improving construction techniques and specifications.
    - The study contributes to a better understanding of the quality of newly installed concrete stormwater pipes in New Zealand.

Overall, the study provides a valuable contribution to the field of stormwater infrastructure assessment, highlighting the importance of standardized reinforced concrete pipe condition assessment methodologies, accurate data interpretation, and contextual analysis.

KEYWORDS

Concrete Pipes, CCTV Inspection, Installation Quality Assurance.

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