Co-UDlabs

Building Collaborative Urban Drainage research Labs communities

D07.3 Report on how to create common European in-pipe defect scenarios

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Table of Contents

Background: about the Co-UDlabs Project

Co-UDlabs is an EU-funded project aiming to integrate research and innovation activities in the field of Urban Drainage Systems (UDS) to address pressing public health, flood risks and environmental challenges.

Bringing together 17 unique research facilities, Co-UDlabs offers training and free access to a wide range of high-level scientific instruments, smart monitoring technologies and digital water analysis tools for advancing knowledge and innovation in UDS.

Co-UDlabs aims to create an urban drainage large-scale facilities network to provide opportunities for monitoring water quality, UDS performance and smart and open data approaches.

The main objective of the project is to provide a transnational multidisciplinary collaborative research infrastructure that will allow stakeholders, academic researchers, and innovators in the urban drainage water sector to come together, share ideas, co-produce project concepts and then benefit from access to top-class research infrastructures to develop, improve and demonstrate those concepts, thereby building a collaborative European Urban Drainage research and innovation community.

The initiative will facilitate the uptake of innovation in traditional buried pipe systems and newer green-blue infrastructure, with a focus on increasing the understanding of asset deterioration and improving system resilience.

List of acronyms

Acronym / Abbreviation	Meaning / Full text
CIPP	Cured-in-Place-Pipe
DWA	Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (German Association for Water, Wastewater and Waste)
EDPM	ethylene-propylene-diene rubber
IKT	IKT – Institut für Unterirdische Infrastruktur (Institute for Underground Infrastructure)
OFWAT	Office of Water Services (Water Services Regulation Authority of UK)
USFD	University of Sheffield - Department of Civil and Structural Engineering

1. Executive summary

This report is aimed at academic researchers, water utility engineers and R&D engineers in the pipe repair supply chain who need to (i) understand the impact of defects on pipe performance, and (ii) to provide evidence on the effectiveness and robustness of different in-pipe repair technologies.

In-pipe defect surrogates have been employed in academic research studies and applied research studies that have been used to develop in-pipe repair technologies (e.g. cured-in-place-pipe pipe repair systems) and validate then to objectively measure the performance of different repair technologies. This allows water utilities to make evidence based decisions on what repair technology to adopt. Suitable in-pipe defect surrogates are also required in the development of emerging in-pipe inspection technologies.

This report describes a range of in-pipe surrogate defects that are mapped against the EN 13508-2, which is the EN that is widely used in Europe to characterise the range of specific defects commonly found in sewers and urban drainage systems. The report describes how surrogate defects are mapped against EN 13508-2 defect codes. The development of the surrogate defects has involved significant technical input from water utilities, to ensure acceptance of the laboratory defects as effective surrogates for similar defects observed in real sewer and drainage pipes. The report also describes how the laboratory defects can be manufactured so allowing laboratories to manufacture consistent defects that have been accep0ted by water utilities as being appropriate surrogates for typical in-pipe defects that have been mapped onto the most widely accepted defect coding system.

The report offers advice to laboratories about how to select defects from this report, with a strong emphasis that any study needs to clarify its aim so that a suitable laboratory surrogate defect is selected for each study.

2. Introduction

Sewer and drainage networks are large and complex and contain a range of underground assets, which are subject to a range of pressures: changing population and wastewater inputs, continually changing stormwater inputs caused by intense rainfall due to changing climatic conditions and the influence of soil and traffic loading conditions. This means that identifying the impact that individual assets that have deteriorated so badly so as to cause service failures is very difficult.

There have been a small number of academic studies that have developed in-pipe defects to examine either defect formation processes or the capability of different sensing technologies to identify and measure in-pipe defects. Some lack complexity and scale, and simulate the pipe defect in a simplistic manner, e.g. the small scale experiments of Guo et al., 2013, and Tang et al. (2022) when studying the impact of pipe exfiltration on the erosion of surrounding soil, and others have used small scale pipes with poorly described defects for example Khan and Patil (2018) in their testing of acoustic methods to locate and characterise in-pipe cracks. Some studies have recovered damaged pipe sections to replicate the reality of the in-pipe sewer environment, for example the laser inspection testing of Lepot et al. (2016). Typically academic studies use small scale surrogates that lack the complexity of the full scale system, or at such a small scale that the replication of full scale processes can be questions. An exception to this situation is the work of Allouche et al., (2014) who in their study on the performance of CIPP liners actively engaged with water utilities and used five samples obtained from recovered pipe section, ensuring realism and confidence amongst the end user community of their results.

A DWA survey (Berger et al., 2020) described that "Intruding or defective connection" (27.3 %) followed by "Fissure" (25.7 %) were the most frequent type of structural pipe damage (see figure 1). In the UK, there has been significant focus on intermittent operational defects such as blockages, because of their linkage to property flooding. This has resulted in UK water companies being set targets for blockage reduction by the UK regulator (The Water Services Regulation Authority, OFWAT).

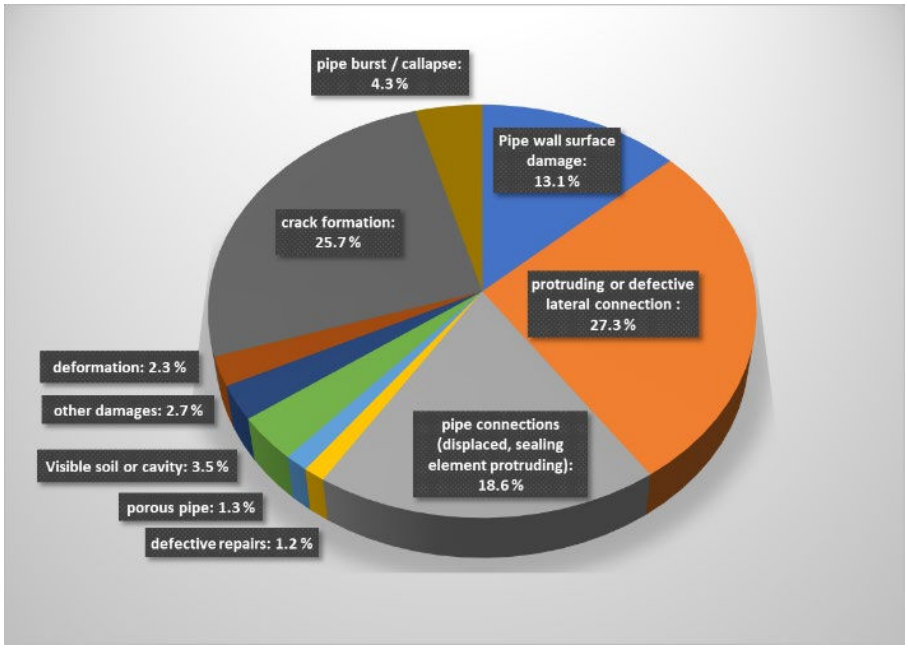


Figure 1: Distribution of typical defects of the sewerage system in Germany (results of the DWA-Survey)

When rehabilitating sewers and drainage pipes, a basic distinction is made between renewal, renovation and repair. DWA reported that of interventions to address defects, renewal is 24.2 %, repair is 51.1 % and renovation is 24.7 %. The DWA survey estimate that the average cost of renewal was 1,794 €/m, 399 €/m for renovation and 112 €/m for repair. In view of the figures, it is clear that robust methods to determine pipe condition, based on characterizing defects is of high importance if appropriate decisions are to be made on renewal/renovation or repair of sections of a network if adequate performance is to be achieved.

In view of the ageing sewerage system in Europe, not only measures by the network operators, such as the rehabilitation or renewal of this infrastructure, are required, but also experimental research to understand how defects develop with time. This knowledge is required especially with regard to the development of new improved strategies for the maintenance and operation of the sewerage system, it makes sense to carry out scientific studies that aim, for example, at

- the performance of procedures for defect inspection, condition assessment and rehabilitation,
- the development of new techniques for defect inspection, condition assessment and rehabilitation,
- understanding the processes that control the deterioration of defects,
- understanding the impact of defects on the functionality, stability and operation of sewer and drainage networks, (e.g. hydraulic capacity and flood risk)
- understanding the impact that defects can have on the environment through the release of wastewater and storm water (e.g. soil, groundwater).

In this context, it is important how a defect can be produced in the laboratory so that it reflects reality in a suitable way and is also reproducible so that data collected in different studies can be comparable. This is important when defect based laboratory studies are used to examine the performance of different inspection, and repair and refurbishment technologies.

IKT - Institute for Underground Infrastructure has many years experience in testing in-pipe repair and refurbishment technologies, requiring the creation of representative and reproducible defects in a laboratory environment. However, in IKT projects involving network operators from other countries (e.g. Belgium, The Netherlands, UK), it became clear that many of defects in Germany (see figure 1) are also frequently observed in these other countries. The main focus of the research projects was on comparative tests of rehabilitation and inspection techniques for sewers. For this purpose, test sections of sewage pipes, manholes and connections were constructed in the laboratory for specific questions and provided with typical defects (damage patterns). A steering committee predominantly consisting of regional network operators from North Rhine-Westphalia (e.g. Municipalities, Water Companies, Water associations), which accompanied any project, defined typical damage patterns depending on the respective issue of each project. In this way, the practical relevance could be ensured directly. In some cases, however, typical defects from other countries were also taken in account und the list of defects had been supplemented regarding this. At the University of Sheffield there have been a number of studies to support low cost sensor development to locate and characterise operational defects such as blockages in improved inspection systems (Yu et al., 2021). These studies

have always involved input from UK water utilities to ensure the relevance of the laboratory defects used to test individual sensing technologies.

The following catalogue and defect descriptions are addressing the requirement on "How to create common European in-pipe defect scenarios" it is intended to provide orientation with regard to the simulation of reproducibility of in-pipe defects on a scale of 1:1 for experimental research in a large-scale laboratory.

However, it must be taken into account that these defects were developed depending on certain scientific questions for specific studies. It must therefore always be considered as to what extent the arrangement and expression of this defect is suitable for any respective study aims.

Table 1 gives an overview of typical defects with reference to the experimental research of IKT and UFSD regarding simulation at a full-scale laboratory.

Table 1: Typical in-pipe defects organised according to EN 13508-2 describing their form and how to create such defects at a laboratory scale

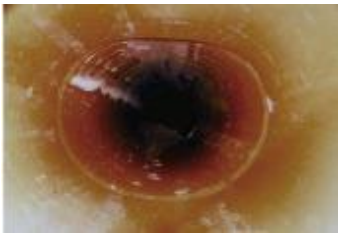
Defect	code*	Reference to research projects with creation of defect published by IKT	Page
Deformation	BAA	Rehabilitation of rising mains (Bosseler/Ulutas, 2022), Profiled large-diameter plastic pipes (Bosseler/ Sokoll, 2005), Inspections systems for property drainage (Bosseler, Kaltenhäuser, 2005)	12, 13
Fissure	BAB	Rehabilitation of house connection pipes using (CIPP-)short liners (IKT, 2018) Inspections systems for property drainage (Bosseler, Kaltenhäuser, 2005), Repairing methods for sewers (DN 200 – DN 600) (Bosseler/Harting, 2009) Rehabilitation of rising mains (Bosseler, Ulutas et al, 2022)	14, 15
Break/Collapse	BAC	Rehabilitation of house connection pipes using (CIPP-)short liners (IKT, 2018) Repairing methods for sewers (DN 200 – DN 600) (Bosseler/Harting, 2009) Inspections systems for property drainage, (Bosseler, Kaltenhäuser, 2005) Rehabilitation of rising main (Bosseler, Ulutas et al, 2022)	15
Defective brickwork or masonry	BAD	*These defects "defective brickwork or masonry" (BAD) and "Missing mortar" (BAE) have not been created at IKT lab so far. Within the framework of a current national research project with the topic CIPP rehabilitation corresponding defects for lab are currently being developed. (BR DÜS, 2020; IKT, 2020)*	
Missing mortar	BAE		
Surface damage	BAF	Rehabilitation of rising mains (Bosseler, Ulutas et al, 2022)	17

Defect	code*	Reference to research projects with creation of defect published by IKT	Page
Intruding connection	BAG	Rehabilitation of lateral connections (Bosseler/Ulutas, 2014)	18
Defective connection	BAH	Rehabilitation of lateral connection (Bosseler/Ulutas, 2014), Repairing methods for lateral connection (Bosseler/Kaltenhäuser, 2004)	18
Intruding sealing material	BAI	*This defect has not been created at the IKT or USFD laboratory so far.*	
Displaced joint	BAJ	Rehabilitation of house connection pipes using (CIPP-)short liners (IKT, 2018), Rehabilitation of rising mains (Bosseler, Ulutas et al, 2022), Inspections systems for property drainage (Bosseler/ Kaltenhäuser, 2005)	21
Lining observation	BAK	*This defect has not been created at the IKT or USFD laboratory so far.*	
Defective repair	BAL	*This defect has not been created at the IKT or USFD laboratory so far.*	
Weld failure	BAM	*This defect has not been created at the IKT or USFD laboratory so far.*	
Porous pipe	BAN	*This defect has not been created at the IKT or USFD laboratory so far.*	
Soil visible through defects	BAO	Rehabilitation of house connection pipes using (CIPP-)short liners (IKT, 2018), CIPP liners for house connection pipes (Bosseler/Redmann, 2010)	23
Void visible through defects	BAP	Rehabilitation of house connection pipes using (CIPP-)short liners (Bosseler/Redmann, 2010), CIPP liners for house connection pipes (IKT, 2018)	23
Roots	BBA	*A simulation of the damage pattern is not possible. According to the report (Stützel/Bosseler 2004), test methods for determining the root resistance of pipe joints are usually based on the assumption of a direct correlation between the size of the contact pressure of the seal and the root resistance. Root growth is to be prevented by the contact pressure of the seal in the area of the pipe joint. More information on the determination of the contact pressure on pipe joints, also under the influence of shear loads, can be found in the report.*	
Attached deposits	BBB	Rehabilitation of rising mains (Bosseler, Ulutas et al, 2022), Testing sewer cleaning procedure and equipment (Bosseler/Schlüter, 2004), Testing acoustic sewer sensors (Romanova, 2013)	25
Settled deposits	BBC	Rehabilitation of rising mains (Bosseler, Ulutas et al, 2022), Testing sewer cleaning procedure and equipment (Bosseler/Schlüter, 2004)	25
Ingress of soil	BBD	*This defect has not been created at the IKT or USFD laboratory so far.*	
Other obstacles	BBE	-	

Defect	code*	Reference to research projects with creation of defect published by IKT	Page
Infiltration	BBF	CIPP liners for house connection pipes (IKT, 2018), Repairing methods for sewers (DN 200 – DN 600) (Bosseler/Harting, 2009)	226
Exfiltration	BBG	Rehabilitation of rising mains (Bosseler, Ulutas et al, 2022)	27

3. Catalogue "How to create common in-pipe defects?"

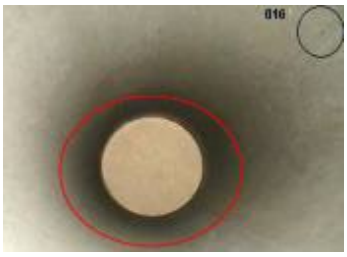
1.1 Deformation (Code: BAA)



(Source: EN 13508-2, 2011).

Description according to EN 13508-2: The cross sectional shape of the pipeline has been deformed from its original shape.

Creation for laboratory tests (examples)



requirement profile: **rehabilitation of rising mains**
steel pipe, ovalisation by 6 %

(Bosseler/ Ulutas, 2022)

requirement profile: **Test concept for checking the deformation behaviour (short-term test)**
plastic pipe DN 2000 with lateral house connections, ovalisation by 3 %

(Bosseler/ Sokoll, 2005)

requirement profile: **Test concept for checking the deformation behaviour (short-term test)** plastic pipe DN 2000 with lateral house connections, ovalisation by 3 %

(Bosseler/Sokoll, 2005)

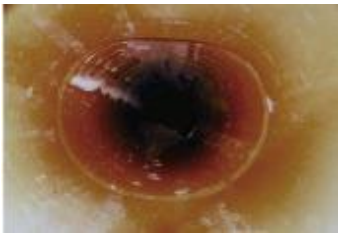
requirement profile: **Test concept for checking the deformation behaviour (short-term test)**
plastic pipe DN 2000 with lateral house connections, ovalisation by 9 %

(Bosseler/ Sokoll, 2005)

requirement profile: **Test concept for checking the deformation behaviour (long-term test)**
plastic pipe DN 2000 with lateral house connections, ovalisation by 9 %

(Bosseler/ Sokoll, 2005)

1.1 Deformation (Code: BAA)



(Source: EN 13508-2, 2011).

Description according to EN 13508-2: The cross sectional shape of the pipeline has been deformed from its original shape.

Creation for laboratory tests (examples)

requirement profile: **Test concept for checking the deformation behaviour and the tightness of the lateral connection during deformation, with braced lateral connection**

plastic pipe DN 2000 with lateral house connections, ovalisation by 6 %

(Bosseler/Sokoll, 2005)

requirement profile: **inspections systems for property drainage**

plastic pipe (PVC), DN 100, vertical deformation 10%

(deformation due the requirement profile visual impact)

(Bosseler/Kaltenhäuser, 2005)

Procedure for creation: **vertical or horizontal compression by using a multi-axial pressure portal (with and without tendons).**

1.2 Fissure (Code: BAB)

(Source: MKULNV, 2014)
Cracks or fracture is visible.

Creation for laboratory tests (examples)

 requirement profile: **rehabilitation of house connection pipes using (CIPP-) short liners** stoneware pipe, expansion: 45 x 10 cm, crack width: 4 mm (IKT, 2018)	 requirement profile: **inspections systems for property drainage** stoneware pipe DN 100, transverse crack, length approx. 20 cm (Bosseler/Kaltenhäuser, 2005)	 requirement profile: **inspections systems for property drainage** stoneware pipe DN 100, longitudinal crack, length approx. 30 cm (Bosseler/Kaltenhäuser, 2005)
 requirement profile: **Repairing methods for sewers (DN 200 – DN 600)** stoneware pipe DN 200, crack branching starting from the springline, expansion: approx. 100 x 20 cm (Bosseler/Harting, 2009)	 requirement profile: **Repairing methods for sewers (DN 200 – DN 600)** stoneware pipe DN 200, longitudinal crack in the crown of the pipe joint, total length: approx. 20 cm (Bosseler/Harting, 2009)	 requirement profile: **Repairing methods for sewers (DN 200 – DN 600)** concrete pipe, transverse crack in the middle of the pipe up to under both springlines (Bosseler/Harting, 2009)
 requirement profile: **Repairing methods for sewers (DN 200 – DN 600)** concrete pipe, longitudinal crack in the pipe crown starting from the socket, length approx. 100 cm longitudinal crack in the springline starting from the socket, length approx. 100 cm (Bosseler/Harting, 2009)	 requirement profile: **Repairing methods for sewers (DN 200 – DN 600)** concrete pipe, longitudinal crack in the crown of the pipe joint, total length approx. 20 cm (Bosseler/Harting, 2009)	 requirement profile: **Rehabilitation of rising mains** longitudinal crack. Due to the change in condition, a complete destruction of the old pipe with complete loss of the old pipe of the old pipe is simulated. (Bossler/Ulutas, 2022)

Procedure for creation:
- **creation with a saw adapted for the pipe material,**
- **position, length and width of the cut depending on requirement profile**

1.3 Break / Collapse (Code: BAC)

(Source: MKULNV, 2014)
The pipe is broken or has collapsed.

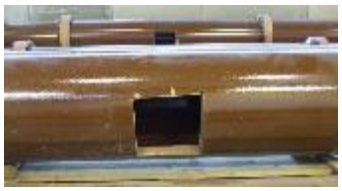
Creation for laboratory tests (examples)

requirement profile: R**ehabilitation of house connection pipes using (CIPP-) short liners**
Stoneware pipe, expansion in longitudinal direction: 25 cm, piece of spigot end is inserted

(IKT, 2018)

requirement profile: R**ehabilitation of house connection pipes using (CIPP)-short liners**
stoneware pipe DN 150, missing shard (approx. ½ x 10 x 5 cm)

(IKT, 2018)



requirement profile: **Repairing methods for sewers (DN 200 – DN 600)**
stoneware pipe DN 200, breakout in the middle of the pipe below the springline (approx. 20 x 20 cm

(Bosseler/Harting, 2009)

requirement profile: **Repairing methods for sewers (DN 200 – DN 600)**
concrete pipe, lateral breakout in a distance of approx. 50 cm from the socket (diameter: 5 cm)

(Bosseler/Harting, 2009)

requirement profile: I**nspections systems for property drainage** stoneware pipe DN 100, shard formation

(Bosseler/Kaltenhäuser, 2005)

Requirement profile: R**ehabilitation of rising mains**
steel pipe, shard load, the change in condition simulates the pressure of an old pipe fragment is simulated (F = 300 N, shard plunger = ø shaft 6 mm / ø tip 2 mm)

(Bosseler/ Ulutas, 2022)

Procedure for creation:
- **creation with a (hole) saw adapted to the pipe material,**
- **position, length and width of the cut depending on requirement profile**

1.4 Defective brickwork or masonry (Code: BAD)

(Source: EN 13508-2, 2011)

Description according to EN 13508-2: Individual bricks or masonry units from the fabric of a brick or masonry drain or sewer has moved from their original position.

Procedure for creation:

This defect of brickwork or masonry defect has not been created at the IKT laboratory so far. Within the framework of a current national research project with the topic CIPP rehabilitation (IKT, 2020), a corresponding defect for laboratory testing is currently being developed.

1.5 Missing mortar (Code: BAE)

(Source: EN 13508-2, 2011)

Description according to EN 13508-2: All or part of the mortar from brickwork or masonry is missing.

Procedure for creation:

This defect of brickwork or masonry has not been created at the IKT laboratory so far. Within the framework of a current national research project with the topic CIPP rehabilitation (IKT, 2020), a corresponding defect for lab is currently being developed.

1.6 Surface damage (Code: BAF)

(Source: MKULNV, 2014)

Description according to EN 13508-2: The surface of the pipeline has been damaged by chemical (including corrosion of metal pipes) or mechanical action (abrasion).

Creation for laboratory tests (examples)

requirement profile: **rehabilitation of rising mains** (Bosseler/Ulutas, 2022)

abrasion: a recess along the bottom invert of the pipe, in which 6x individual holes, each with a ø 10 mm are evenly distributed.

Dimensions of the invert: Width = 30 mm, Depth = 5.1 mm

Defect has been created for the loading type of “mechanical action” (abrasion). Defect for the loading type of “chemical action” has not been created at the IKT laboratory so far.

Procedure for creation:

- **creation with a saw and a drilling machine**

1.7 Intruding connection (Code: BAG)

(Source: MKULNV, 2014)

Description according to EN 13508-2: A connecting pipe projecting into the pipeline, obstructing the cross-sectional area.

Creation for lab tests (examples)

 requirement profile: **rehabilitation of lateral connections**, intruding lateral connection of a stoneware pipe (DN 150) into a concrete pipe (DN 300), protruding max. 1 cm, lateral pipe is intruding through on open hole (Bosseler/Ulutas, 2014)	 requirement profile: **rehabilitation of lateral connections**, intruding lateral connection of a stoneware pipe (DN 150) into a stoneware pipe (DN 300), protruding max. 1 cm, lateral pipe is intruding through on open hole (Bosseler/Ulutas, 2014)	

Procedure for creation:

- **using a drilling machine**

1.8 Defective connection (Code: BAH)

(Source: MKULNV, 2014)

Description according to EN 13508-2: A connection is defective.

Creation for lab tests (examples)

requirement profile: **repairing methods for lateral connection** (Bosseler/Kaltenhäuser, 2004)

Improperly installed connecting piece with severe damage with cracks and shard formation, left: exterior view before installation, right: interior view after installation
(main sewer: stoneware pipe DN 250, connecting sewer: stoneware pipe DN 150)

requirement profile: **rehabilitation of connections**

Improper (leaking) connection, in the transom of the main sewer 45° deviation from the main sewer longitudinal axis, stoneware pipe DN 150 is put on the outside of the concrete pipe (main sewer) laterally

Improper (leaking) connection, in the crown of the main sewer 90° deviation from the main sewer longitudinal axis, stoneware pipe DN 150 is put into the concrete pipe (main sewer) up to half the wall thickness

Improper (leaking) connection between transom and crown of the main sewer, 45° deviation vertical to longitudinal axis of the main sewer, stoneware pipe DN 150 is put into the concrete pipe (main sewer, protruding max. 1 cm)

Procedure for creation:

- **using sawing and drilling equipment matched to the pipe material**

1.9 Intruding sealing material (Code: BAI)

(Source: MKULNV, 2014)

Description according to EN 13508-2: All or part of the material used to seal a joint between two adjacent pipes is intruding into the pipeline.

Creation for lab tests (examples)

This defect has not been created at the IKT or UFSD laboratories so far.

1.10 Displaced joint (Code: BAJ)

(Source: MKULNV, 2014)
description according to EN 13508-2: Adjacent pipes are displaced from their intended position in relation to each other.

 Requirement profile: **rehabilitation of house connection pipes using (CIPP-)short liners** Expansion: ≥ 20 mm, rehabilitation under groundwater inflow at approx. 50% of the pipe height (Bosseler/Redmann, 2010)	 Requirement profile: **rehabilitation of rising mains** axially displaced socket joint, with 31 mm longitudinal offset (circumferential) (Bosseler/Ulutas, 2022)	 Requirement profile: **inspections systems for property drainage** stoneware pipe DN 150, Vertical offset (sealing ring removed) (Bosseler/Kaltenhäuser, 2005)
 defect of the requirement profile for the **rehabilitation of house connection pipes using (CIPP-)short liners**[Error! Bookmark not defined.] Expansion: ≥ 9°, rehabilitation under groundwater inflow at approx. 50% of the pipe height (Bosseler/Redmann, 2018)		

Procedure for creation:

- **creation with a (hole) saw adapted to the pipe material,**
- **position, length and width of the cut depending on requirement profile**

1.11 Lining observation (Code: BAK)
 (Source: EN 13508-2, 2011) Description according to EN 13508-2: The lining of the pipeline is observed to have one of the following features."
This defect has not been created at the IKT laboratory so far.

1.12 Defective Repair (Code: BAL)
Description according to EN 13508-2: A repair has been carried out on the drain or sewer which now has a defect. The lining of the pipeline is observed to have one of the following features."
This defect has not been created at the IKT or UFSD laboratory so far.

1.13 Weld failure (Code: BAM)
Description according to EN 13508-2: A failure in a weld in the fabric of the pipeline.
This defect has not been created at the IKT or UFSD laboratories so far.

1.14 Porous pipe (Code: BAN)
Description according to EN 13508-2: The pipe material is seen to be porous.
This defect has not been created at the IKT or UFSD laboratories so far.

1.15 Soil/Void visible through defects (Code: BAO/BAP)

(Source: MKULNV, 2014)
Description according to EN 13508-2: The soil outside the pipe is visible through a defect / a void outside the pipe is visible through a defect.

Creation for lab tests (examples)

requirement profile: **rehabilitation of house connection pipes using (CIPP-)short liners**
Stoneware pipe, expansion in longitudinal direction: 25 cm, piece of spigot end is inserted

(IKT, 2018)

requirement profile: **rehabilitation of house connection pipes using CIPP-liners**
stoneware pipe DN 150, missing shard (approx. ½ x 10 x 5 cm)

(IKT, 2018)

Procedure for creation:

1. creation the holes with a (hole) saw adapted to the pipe material,

2. wrapping the damaged areas with a gravel pack and wrapping with a water-permeable geotextile (see below),

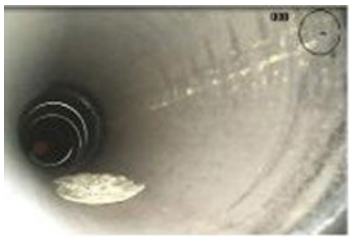
3. covering with soil

1.16 Roots (Code: BBA)
 (Source: MKULNV, 2014) description according to EN 13508-2: Roots of trees or other plants growing into the pipeline through joints, defects or connections.
Creation for lab tests (examples)
A simulation of the damage pattern is not possible. According to the report Stützel/Bosseler 2004, test methods for determining the root resistance of pipe joints are usually based on the assumption of a direct correlation between the size of the contact pressure of the seal and the root resistance. Root in growth is to be prevented by the contact pressure of the seal in the area of the pipe joint. More information on the determination of the contact pressure on pipe joints, also under the influence of shear loads, can be found in the report Stützel/Bosseler 2004.

1.17 Attached/Settled deposits (Code: BBB/BBC)


(Source: MKULNV, 2014)
description according to EN 13508-2: Material attached to the wall of the pipeline./ Deposited material in the invert of the pipeline.

Creation for laboratory tests tests (examples)



requirement profile: **rehabilitation of rising mains**

Reduction of the vertical dimension by 6 % (12 mm), length: 30 cm
Deposit with rough surface attached firmly to the pipe wall.

(Bosseler/Ulutas, 2022)

requirement profile: **testing sewer cleaning procedure and equipment**

Using model sediments to reduce vertical dimension by 15, 30 and 45% (PVC pipes, DN800)

(Bosseler/Schlüter, 2004)

requirement profile**: testing acoustic sewer sensors**
Using model blockages to reduce vertical dimension by 10 and 20% (PVC and Clay 300mm dia pipes) Additional units can be used to adjust length of blockage

(Romanova, 2013)

requirement profile**: testing acoustic sewer sensors**

Using sand filled blockages to reduce areal dimension by 5, 10, 15 and 20% (PVC and Clay 300mm diameter pipes) Units are sand contained in acoustically porous material. Sand can be dry or wetted to different levels of saturation

(Romanova, 2013)

Procedure for creation:

- **Sticking on defined deposits or sand insertion**
- **Creation of cement pipe inserts using mould**
- **Creation of sand filled blockages, use defined mass and acoustically transparent covering. Blockage pulled into pipe at defined location.**

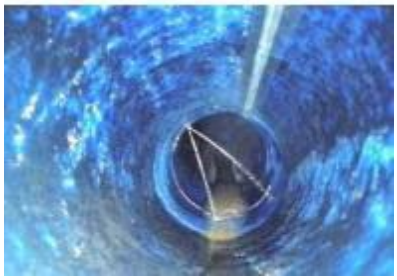
1.18 Infiltration (Code: BBF)

(Source: MKULNV, 2014)
description according to EN 13508-2: The ingress of water through the wall of the pipe or through joints or defects.

Creation for lab tests (examples)

Requirement profile: testing **CIPP liners for house connection** (Bosseler/Redmann, 2010)

Installation of stoneware pipes, DN 150 (with missing EDPM seals in the pipe joint) and backfilling with soil in IKT´s Large Testing facility (LTF), groundwater simulation



requirement profile: **Repairing methods for sewers (DN 200 – DN 600)**
stoneware pipe DN 300, leaking socket: plugging together the socket and shortened spigot end with a EDPM sealing ring with imperfections, installation of the pipes in a sealed test rig, filling the test rig with water.

(Bosseler/Harting, 2009)

Procedure for creation:

- **Simulating a leaking pipe joint by omitting the EDM seal (left side pictures) or using a shortend spigot end and an EDPM seal with imperfections (right side picutres)**
- **Application of outside water pressure (variation of water pressure by changing the water column), in contact with soil or without soil**

1.19 Exfiltration (Code: BBG)		
Description according to EN 13508-2: Visible leakage of flow out of the pipeline.		
Creation for lab tests (examples)		
 requirement profile: **Rehabilitation of rising mains** leaking joint: 4x leaking flange joint (For each leaking flange joint the seal was removed by 5 mm at each third points (4, 8, 12 o'clock). (Bosseler/ Ulutas, 2022)		
Procedure for creation: • **Creation of leakage in the pipe or in the joint** • **Application of water pressure (e. g. similar to leak tests with water according to EN 1610) or water flow in the pipe**		

4. Conclusions

This report contains a list of laboratory defects that have been developing in collaboration with water utilities. This ensures that there form has achieved recognition from water utilities so provides a strong level of credibility. The list has been mapped onto the defect coding of the most commonly used defect mapping system used throughout Europe. There are similarly structured defect coding systems used throughout the world (e.g USA/Canada).

The list of laboratory defects includes advice for other laboratories to be able to manufacture similar defects so that comparable studies can be planned and implemented.

In terms of using these defects in a study, it is important that the scientific question of any study is clearly defined so that an appropriate laboratory defect can be selected. The execution of the damage should be based on the characteristics of the corresponding damage pattern of the EN 13508-2, but having in mind that the defect can be reproducible for laboratory.

Reproducibility is important, if a certain damage pattern is to be generated several times for the same scientific question, once a defect pattern is determined a template should be used, and the same tools and ideally the same staff should be used. The complete process of decision-making, planning and installation of defects should be documented in detail. This allows the results of the study to be justified to water utility end users.

For the simulation of defects for investigations on the performance of rehabilitation or inspection systems, it has been found that the following aspects are important:

- Limits of the application of the rehabilitation or inspection systems. The defect must be capable of being remediated or inspected with the available remediation or inspection methods.
- The defect must sufficiently complex to reflect the major aspects of practical conditions.
- Relevance of the defect in terms of its frequency and location of occurrence.
- Experience of Network operators/Municipalities/Water companies is important, projects that rely on laboratory defect testing are advised to have steering committees including a strong representation of end users. For example in IKT projects: A group of municipalities had strong involvement in decisions on which defects are of interest and what defects should look like (based on their long-time experience). Decisions on defect manufacture was determined by means discussion and voting, evidenced by surveys. This activity ensure strong confidence that the laboratory defects (as described above) have a strong acceptance in the end user community.

The examples in the above catalogue “how to create common European in-pipe defect scenarios” should serve as recommendations, their use should always map to the aim of any study and strong end users involvement in any laboratory based study is recommended.

5. References

Allouche E., Alam S., Simicevic J., Sterling R., Condit W.., Matthews J., Selvakumar A. (2014) A pilot study for retrospective evaluation of cured-in-place pipe (CIPP) rehabilitation of municipal gravity sewesr. Tunnellling and Underground Space Technology 39, 82-93.

ATV DVWK A 127 (2000). Statische Berechnung von Abwasserkanälen und -leitungen. 3. Korrigierte Auflage (Structural analysis of sewers and drains. 3rd corrected edition). ISBN 978-3-933707-37-6. In German.

BR DÜS (2020). Zuwendungsbescheid Projektförderung der Bezirksregierung Düsseldorf. Projektlaufzeit: 16.06.2020 bis 31.12.2024 (Project funding notification from the Düsseldorf district government. Project duration: 16.06.2020 to 31.12.2024). In German.

Bosseler, B.; Harting, K.; Färber, D. (2009). IKT-Warentest Reparaturverfahren für Hauptkanäle (IKT Comparative Test „Repairing methods for sewers"). IKT - Institute for Underground Infrastructure. https://www.ikt.de/downloads/warentest-berichte/ (accessed 13/04/2023). In German.

Bosseler, B.; Kaltenhäuser, G. (2004). IKT-Warentest – Reparaturverfahren für Anschlusstutzen (Reparing methods for lateral connections). IKT – Institut für Unterirdische Infrastruktur. https://www.ikt.de/website/down/c0072langbericht.pdf (accessed 13/04/2023). In German.

Bosseler, B.; Kaltenhäuser, G. (2005). IKT-Warentest „Inspektionssysteme für Grundstücksentwässerungsnetze" (IKT Comparative Test "Inspection system for property drainage network". IKT - Institute for Underground Infrastructure. https://www.ikt.de/website/down/f0116langbericht_inspektion.pdf (accessed 13/04/2023). In German.

Bosseler, B.; Redmann, A.; et al. (2010). IKT-Warentest Hausanschlussliner (CIPP liners for house connection pipes). IKT – Institut für Unterirdische Infrastruktur. Gelsenkirchen. https://www.ikt.de/downloads/warentest-berichte/ (accessed 13/04/2023). In German.

Bosseler, B.; Schlüter, M. (2004). Kanalreinigung – Düsen, Drücke, Hochdruckstrahle (Sewer cleaning - nozzles, pressures, high-pressure jets). IKT – Institut für Unterirdische Infrastruktur. Gelsenkirchen, Dezember 2004. https://www.ikt.de/downloads/forschungsberichte/ (accessed 13/04/2023). In German.

Bosseler, B; Sokoll, O. (2005). Profilierte Großrohre aus Kunststoff – Praxiserfahrungen und Prüfkonzepte (Profiled large-diameter plastic pipes – pratctical experience and testing concepts). IKT - Institute for Underground Infrastructure.

https://www.ikt.de/website/down/f0120langbericht.pdf (accessed 13/04/2023). In German.

Bosseler, B.; Ulutas, S; et al. (2014). IKT-Warentest Stutzensanierung in Fremdwassergebieten. Stutzen-Einbindung und Stutzen-Reparatur (Rehabilitation of lateral connection in areas with extreneous water). IKT – Institut für Unterirdische Infrastruktur. https://www.ikt.de/wp-content/uploads/2015/01/IKT-Warentest-Stutzen-Sanierung-Endbericht.pdf (accessed 13/04/2023). In German.

Bosseler, B.; Ulutas, S; et al. (2022). IKT-Warentest Sanierungsverfahren für Abwasserdruckleitungen – Klasse-A-Liner (IKT Comparative Test Rehabilitation methods for waste water pressure pipes). IKT - Institute for Underground Infrastructure. https://www.ikt.de/wp-content/uploads/2023/03/Endbericht-WT-DL.pdf (accessed 13/04/2023). In German.

Berger, C.; et al. (2020). Zustand der Kanalisation in Deutschland. Ergebnisse der DWA-Umfrage 2020. Sonderdruck aus KA Korrespondenz Abwasser, Abfall. 67. Jahrgang. Heft 12/2020, S. 939-953. https://de.dwa.de/files/_media/content/03_THEMEN/Entwaesserungssysteme/Kanalumfrage/Zustand-der-Kanalisation-2020.pdf (accessed 13/04/2023). In German.

DWA A 127-1 (2022). Statische Berechnung von Entwässerungsanlagen - Teil 1: Grundlagen. DWA-Regelwerk (Structural analysis of drainage systems - Part 1: Basics. DWA rules and regulations). In German.

EN 13508-2 (2011). Investigation and assessment of drain and sewer systems outside buildings - Part 2: Visual inspection coding system. English Version. Irish Standard I.S. EN 13508-2:2003+A1:2011.

Guo S., Shao Y., Zhu D., Zhang Y. (2013) Physical modelling on sand erosion around defective sewer pipes under the influence of groundwater. Journal of Hydraulic Engineering 139(12) 1247-1257.

IKT (2018). IKT-Warentest „Kurzliner für Hausanschlüsse“ – Auszug aus dem Forschungsbericht (IKT Comparative Test “Short liner for house connection pipes“ – extract from the research report). IKT - Institute for Underground Infrastructure. https://www.ikt.de/wp-content/uploads/2018/10/ikt-warentest-kurzliner-hausanschluesse-bericht.pdf (accessed 13/04/2023). In German.

IKT (2020). Förderantrag „Vergleichende Prüfung der Qualität von Schlauchlining-Verfahren für Hauptkanäle (IKT-Warentest Schlauchliner)“ (Funding proposal: “Comparative testing of the quality of CIPP lining methods for main sewers”). Gerichtet an das Ministerium für Umwelt und Landwirtschaft, Natur- und Verbraucherschutz des Landes Nordrhein-Westfalen (Addressed to the Ministry of Environment and Agriculture, Nature and Consumer Protection of the State of

North Rhine-Westphalia). Antragssteller: Stadt Düsseldorf (Applicant: City of Düsseldorf). Forschungsdienstleister: IKT (Research service provider: IKT). In German.

Khan M.S., Patil R., (2018) Acoustic Characterization of PVC Sewer Pipes for Crack Detection Using Frequency Domain Analysis, 2018 IEEE International Smart Cities Conference (ISC2), Kansas City, MO, USA, 2018, pp. 1-5, doi: 10.1109/ISC2.2018.8656739.

Lepot M., Stanic N., Clemens F.H.L.R Clemens (2017) A technology for sewer pipe inspection (Part 2): Experimental assessment of a new laser profiler for sewer defect detection and quantification. Automation in Construction 73, 1-11.

MKULNV (2014). NRW-Bildreferenzkatalog – Private Abwasserleitungen (Image reference catalogue of North Rhine-Westphalia – private sewage pipes). Ministerium für Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucherschutz des Landes Nordrhein-Westfalen.

https://www.lanuv.nrw.de/fileadmin/lanuv/wasser/abwasser/dichtheit/pdf/Bildreferenzkatalog_Private_Abwasserleitungen.pdf / (accessed 13/04/2023). In German.

Romanova A., (2013) Acoustic Monitoring of Hydraulic Resistance in partially filled pipes, PhD thesis, University of Bradford, UK.

Stützel, T.; Bosseler, B.; et al. (2004). Wurzeleinwuchs in Abwasserleitungen und Kanäle (Root ingroth in waste water pipes and sewers). IKT – Institut für Unterirdische Infrastruktur. Gelsenkrichen. https://www.ikt.de/website/down/f0108langbericht.pdf (accessed 13/04/2023). In German.

Tang Y., Zhu D.Z., Chan D.H., Zhang S. (2022) Physical and analytical modelling of soil loss caused by a defective sewer pipe with different defect locations. Acta Geotechnica, doi:10.1007/s11440-022-01747-7.

Yu Y., Safari A., Niu X., Drinkwater B., Horoshenkov K.V (2021) Acoustic and ultrasonic techniques for defect detection and condition monitoring in water and sewerage pipes: A review, Applied Acoustics, 183, art. no. 108282