Impact of hidden defects on the durability and reliability of gas pipelines in cities

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Abstract. The article describes the methods of improving the durability of new gas pipelines, as well as examines the need of rising the level of inspection security. Reliable gas pipelines is an important safety indicator of people's housing areas and the industrial and commercial organizations work areas. The verification of durability and tightness of gas pipelines is one of the most important inspection, which shows the existence of defects in compliance of the gas pipelines and debt construction technologies and instructions. Detected on time defects influence the number of uncontrolled natural gas leaks in the pipelines. When assessing the impact of hidden defects on the durability and reliability of the gas pipeline, the gas pipeline monitoring process was made, and the defects in the construction of gas pipelines (polyethylene, steel) and fittings were more often detected, the effect of hidden defects of gas pipelines on the safety of pipelines was analyzed. The experiments described in the article were carried out to evaluate the durability and tightness of gas pipelines by simulating the hidden defects on new installed gas pipeline in two sites: Site 1 and Site 2, both places are situated in Latvia. The obtained data was processed and reflected in tables, charts, graphs, and the results were analyzed and summarized in the conclusions, and also proposals are made to improve the problem. In the article is described a calculation methodology, which proves what needs to be improved in order to increase the safety of newly built and reconstructed gas pipelines.

1 Introduction

Currently there is an increase in the gas pipeline construction sector in Latvia, and methods of assembly and quality testing are also developing.

The monitoring organisations are involved in construction from the design of the project to the commissioning of the site. In Latvia, the technical supervision of gas pipeline construction is ensured by representatives of gas pipeline distribution network operator “Gaso”.

The gas pipeline construction monitoring process consists of multiple operations to be tested by network operator engineers: inspection and registration of a building project, inspection of gas pipelines at the site, taking a trench and accepting other communications at the site, verification of the quality of the welding process technologies, inspection of welding and assembly at the site, closure of the pipeline filling and improvement at the installation, inspection of the internal cleanliness of the gas pipeline, removal at the site. Inspection of the strength and tightness of the gas pipeline at the installation, inspection of the project execution documentation and acceptance of the gas pipeline in operation [7].
Checks on pipeline networks are necessary to prevent accidents from causing great harm and damage to people (financial, economic, health and life, etc).

2 Gas pipeline strength tests
The stress test for gas pipelines is one of the most important. It shall demonstrate the safety and operational readiness of the projects envisaged. It is the stress and tightness tests of the gas pipeline that show that there were errors in the construction of gas pipelines and that construction technology and instructions were not followed. The defects detected at the time prevent the uncontrolled number of natural gas leakages (discards) by putting gas pipelines into service.
It also has a big impact on the safe lifestyle of the satellite, not only the external gas pipeline systems, but also the internal gas pipeline systems. Where there are a series of their own factors [10].
Construction works are a complex technological process that starts with project calculations, matching materials and continues through the implementation of complex building physics processes in practical construction activities [1].
In Latvia, nitrogen has been used to check strength and tightness in recent years. The stress and tightness of gas systems shall be tested with manometers having an accuracy class of at least 0.6 and a maximum measurement range of 150% of the test pressure.
The duration of the strength test for external gas pipelines shall be 1 hour during which the pressure is not allowed to fall. [12], [2].
The leakage of underground gas pipelines shall be checked after their backfilling to the markings of the building project. The test pressure shall be maintained prior to the leakage test in the gas pipeline so that the temperature is aligned with the ground temperature. The minimum temperature adjustment duration shall be as follows:
- for a gas pipeline with a notional diameter (DN) of up to 300 mm (inclusive) for 6 hours;
- for a gas pipeline with a notional diameter (DN) above 300 mm to 500 mm (inclusive) for 12 hours;
- for a gas pipeline with a notional diameter (DN) above 500 mm - 24 hours. [10], [18].
During the monitoring process, the following data for the 2016-2018 year have been compiled for the assessment of the strength and tightness of the pipeline system for newly constructed sites (Figure 1):

![Pressure testing statistics](image)

Figure 1. *Site strength and tightness testing 2016-2018 (source AS “Gaso”)[13].

On the basis of aggregated data, it can be concluded how on average 80% of the tested sites have passed the strength and leakage test from the first time, 17% from the second time, and 3% only from the third
time [13]. Dmitri Ohotski years 2015 has also completed the results of calls by AS “Latvijas Gaze” (now AS “GASO”) for his master’s work (to 2012 by 2014) and has concluded that on average 20.84% of the cases of gas leakages have been detected for operating underground gas pipelines [11]. Accident survey allows for analysis of the situation and improvement of emergency work by means such as updating emergency plans, high-quality training of personal and the setting up of modern equipment at sites [17].

This means how, before the new gas pipeline was taken into service, 20% of gas leakages were detected and eliminated.

During the leakage test of the underground gas pipeline, the actual drop in pressure must not exceed the calculated permissible value, which is determined if the pressure is measured in millimetres of the mercury column, using the following formula [12], [10]:

$$\Delta P = \frac{20 T}{d} \left( \Delta P' = \frac{150 T}{d} \right)$$ (1.)

where

- $\Delta P$ – allowable pressure falls (KPa);
- $\Delta P'$ – allowed pressure drop (mm Hg);
- $d$ – the internal diameter of the pipeline (mm);
- $T$ – test time (h).

The actual pressure on the pipeline $\Delta P_f$ (kPa vai mm Hg) during the test shall be calculated using the following formula [10]:

$$\Delta P_f = (P_1 + B_1) - (P_2 + B_2),$$ (2.)

where

- $P_1$ and $P_2$ – indication of the manometer at the beginning and end of the test (kPa or mm Hg);
- $B_1$ or $B_2$ – Barometer readings at the beginning and end of the test (kPa or mm Hg).

If the pipeline consists of pipeline sections with different diameters ($d_1$, $d_2$, $d_3$...$d_n$), the mean internal diameter shall be calculated using the following formula [10]:

$$d = \frac{d_1 l_1 + d_2 l_2 + d_3 l_3 + \cdots + d_n l_n}{d_1 + d_2 + d_3 + \cdots + d_n},$$ (3.)

where

- $d_1$, $d_2$, $d_3$...$d_n$ – internal diameter of the phases of the pipeline (mm);
- $l_1$, $l_2$, $l_3$...$l_n$ – length of the relevant diameter pipeline section (m).

The duration of the leakage test for underground gas pipeline shall be 24 hours. The leak test may be carried out at the same time as the strength test (combined inspection) using the same environment and pressure [10], [12]. However, the required length and volume of the pipelines in metres of the calculation pipelines have not been determined and there is no appropriate methodology for calculating them. The calculation methodology presented in the LBN 242-15 allows for the determination of the permissible loss reduction by calculating the ratio between the test time and the average diameter of the gas pipeline to be inspected. There may be a possibility of leakage that can be classified as “hidden defects” below the limit of allowable losses. In identifying the most important factors affecting the existence of “hidden defects”, a set of the size, length and diameter of the pipelines.

3 Gas pipeline defects

Such defects, which are not detected during the strength and leak test, are called “hidden defects”:

- poor quality of welded compounds [20];
- defects found during transportation and assembly of the pipeline;
- industrial defects of the pipeline;
- pollution which has a negative impact on the quality and integrity of the pipeline connections;
- corrosion of steel pipelines;
- defects in pipeline fittings;
- Failures resulting from third part activities [4], [5], [6].
If the pipe connection is welded to the technology, the joint should be as strong as the pipe [19].

3.1. Poor fusion interface
Cracking down of gas pipelines through the fusion interface which was formed when the oxidation layer from the external surface of a weldable pipeline has been removed unqualitatively (Figure 2a), there was an inappropriate temperature at the welding site (Figure 2b), no purification and degreasing methods [15], the article contains specific defects that resulted from non-application of the technology.

![Figure 2. a - Defect with unremoved oxidation layer, 4073 b - Defect – Cold welding, 4072) [15]](image)

3.2. Welding tank formation
Cracking of gas pipelines during assembly - electrical welding compounds containing voids. A defect in emptiness can result in a structural rupture at the welds sites and cause a stress concentration that can further create a gap. The main causes of the voids are the choking air and no dew point was removed on the outer surface or there has been wet contamination, shown in (Figure 3a) [15].

![Figure 3. a - Welding tank formation, 4074 b - Structural deformation, 4072 [15].](image)

3.3. Structural deformation
Cracking of gas pipelines through a built-in copper heating element wire. Failure of the electrical welding coupling to maintain the expected structure after welding when deviations from the correct pipeline fitting welding fitting fitting. Consequently, the gas pipeline contains bottlenecks filled with the mass of the melting process as a result of the welding process. This mass may pass through cold areas of the fitting outwards or inwards. If the mass is released outwards, it may be visually detected and, if inwards, cannot be detected. Position of the deformation heating element in the same process outwards or inwards running with the mass formed in the melting process (Figure 3b) [15], [14].

4 Hidden defects” in the object
Monitoring of newly constructed gas pipelines was carried out at the construction site in Latvia (hereinafter the Site1). The newly constructed pressure P ≤ 4 bar distribution pipeline and 38 privat house connection to the site. Length of the newly constructed gas pipeline 2844,51 m. Distribution
pipeline: 1841.04 m; DN 50 mm - 1405.23 m and DN 130.8 mm - 435 m and leads DN 25 mm - 1003.47 m. Average diameter of the gas pipeline DN 76.11548 mm (formula 3). Decrease limit \( \Delta P = 47.297 \text{ mmHg} \) (formula 1). The volume of gas pipelines without pressure shall be 9,103142 m\(^3\) (formula 4). Volume of the gas pipeline systems:

\[
v_{\text{syst}} = \frac{\pi \cdot D_n^2}{4} \cdot L \text{ (m}^3\text{)},
\]

where \( \pi \) - 3.14 const;

\( D_n \) – internal diameter (m);

\( L \) – length og the pipeline section (m).

The pipeline inspection was carried out with combined strength and tightness testing (24 hours) and during the test after all obtained for measurements, a “Hidden Defect” was detected in the gas pipeline (Table 1) When reading the test data and making all calculations using the formulae in Chapter 2, the results obtained has not exceed the permissible pressure loss limit.

Table 1. Results of the Site 1 “Work Site”.

| Stages | Test time (hour) | Manometric pressure | Barometric pressure (mmHg) | Allowable loss limit | Actual drop in losses |
|--------|-----------------|---------------------|----------------------------|----------------------|-----------------------|
|        |                 | P1 (bar) | P2 (bar) | P1 (mmHg) | P2 (mmHg) | B1 | B2 | mmHg | mmHg |
| 1      | 24              | 7.092    | 7.031   | 5319     | 5273.25  | 761 | 763 | 47.297 | 43.8 |
| 2      | 24              | 7.127    | 7.091   | 5345.25  | 5318.25  | 762 | 761 | 47.297 | 28.00 |

In Table 1, can be seen that after the results of Stage 1, it is apparent that the allowable loss limit is not exceeded, but in fact two gas leakage sites were found in the pipeline. The results of Stage 2 show that the actual margin of reductions (from 43.8 mmHg to 28.00 mmHg – 36.07%) has changed, preventing gas leaks in the pipeline system. Consequently, it can be concluded that there is a relationship between the diameters, lengths, system volumes that can be verified by formulas and conclusions drawn. An experiment was needed to test this relationship in real terms.

Stankevič N. has mentioned in his book that there should be a certain gas pipe diameter and maximum pipeline inspection length (up to DN 200mm - 12 km, DN 300mm - 8 km, DN 400mm - 6 km, DN 500mm - 5 km) but not clear from how it was calculated [21]. Also, the DVGW standard G 469 (2010) mentions the relationship between the diameter of the gas pipelines to be tested and the maximum length, taking in to account the geometric volume of the pipeline [2]. Also, the methodology for calculating these maximum diameters and lengths is not shown here. Lithuanian Standard Order for Approval of Distribution Pipeline Installation Regulations 2016 May 17 No. 1-162 (2016) takes the maximum length of the gas pipeline test, but the volume only to determine the required stabilization time of the gas pipelines when the gas pipeline is filled with nitrogen and is ready to test for strength and tightness (leakage) [16].

5 Experiment

The experiment was conducted on a new pipeline distribution grid and 11 privat house connection to the site with pressure \( P \leq 100 \text{ mbar} \) in Latvia (hereinafter Site 2). The length of the newly constructed gas pipeline, which has been studied, is 2171.23m. From it distribution gas pipeline - 1969.55m: DN 50mm - 188.83m, DN 73.6mm - 1229.44m, DN 90mm - 42.69m and DN 100mm - 508.59m. Drives - 201.68m: DN 25mm 144.34m and DN 32mm - 57.34m. The average diameter of gas pipelines is DN 79,40831mm (formula 3). Permissible drop limit \( \Delta P = 45.34\text{mmHg} \) (formula 1). The volume of gas pipelines without pressure is 9,9821m3 (formula 4). The pipeline scheme can be seen in Figure 4.
5.1 Preparing a Sie 2 for an experiment

The measuring station was integrated in the system (Figure 5) where the measuring devices (pressure gauge) are installed and the results of the pressure test are read. Inert gas — nitrogen (N2) has been used for pressure testing. The pipeline system is nitrogen-filled, not exceeding the permissible pressure test parameters.

5.2. Description of the experiments progress
Experiment performed in 3 steps:

In step 1, the author reads the pressure data of the pipeline system from the site of the pressure measuring station, using manometers to establish that the pipeline system is airtight.

In step 2, the author opens the shut off valve No 1 and gives a verifiable system pressure to flow interruptor No 1. As a result of the operational principles of the flow interruption, the interruptor No 1 closes. (the flows were interrupted by the principle of action) [3]. Knowing the selected flows disrupted the industrial data in the $V_L$ — (overflow well airflow — $V_L$, l/h < 301 @ 1 bar per hour) and the pressure in the system, the estimated amount of released nitrogen in m³ for 1 hour and 24 hours was calculated [22]:

$$V_L=30*P_n \ l/h$$

where $P_n$ – pressure system by measurement number (bar):

$$V_L=30*7,118=213,54 \ l/h \text{ or } V_L=213,54/1000=0,21354 \ m^3/h.$$

Leakage through the overflow well No 1 simulates the “hidden defect” to be investigated in the system. Experimental time of the leak - 1 hour. After an hour, the pressure in the system at the location of the measuring station is re-measured. Experimental time of the leak - 24 hours. After 24 hours, the pressure in the system at the location of the measuring station is re-measured.

In step 3, the author shall open shut off valve No 1 and 2 and give the system pressure to be checked to the flow interruptors Nos 1 and 2. In the context of the operating principles of the flow transformer, interruptors Nos 1 and 2 shall be closed. Leakages simulating the "hidden defect" system to be investigated shall occur through overflow drills No 1 and No 2. Experimental time of the leak - 1 hour. After an hour, the pressure in the system at the location of the measuring station is re-measured. Experimental time of the leak - 24 hours. After 24 hours, the pressure in the system at the location of the measuring station is re-measured.

The author reads all the data and makes calculations based on the formulae mentioned above, compiling the results in Table 2 [13].

### Table 2. Results of the experimental Site 2.

| Stage | Test time (hour) | Manometric pressure | Barometric pressure (mmHg) | Allowable loss limit | Measurement error 0.1% | Expected drop in losses | Actual drop in losses |
|-------|-----------------|----------------------|----------------------------|---------------------|------------------------|-------------------------|----------------------|
|       | P1 (bar) | P2 (bar) | P1 mmHg | P2 mmHg | B1 | B2 | bar | mmHg | bar | mmHg | bar | mmHg |
| 1     | 1         | nr.1   | 7.29   | 7.29   | 753 | 753 | 7.28 | 0     | 0.0073 | 7.28 | 0 | 0 | 0.00 |
|       | 21.52    | nr.2   | 7.29   | 7.27   | 5466 | 5456 | 7.23 | 40.65 | 0.0073 | 7.28 | 0 | 0 | 0.01 |
| 2     | 1         | nr.5   | 7.12   | 7.11   | 764 | 764 | 7.11 | 0     | 0.0071 | 7.11 | 0.02 | 15.75 | 0.006 |
|       | 24       | nr.9   | 6.91   | 5325   | 5185 | 7.04 | 45.34 | 0.0069 | 6.92 | 0.51 | 395 | 0.19 | 151 |
| 3     | 1         | nr.7   | 7.11   | 7.10   | 764 | 764 | 7.10 | 0     | 0.0071 | 7.10 | 0.04 | 32.25 | 0.01 |
|       | 24       | nr.11  | 6.91   | 6.68   | 5183 | 5012 | 6.85 | 45.34 | 0.0067 | 6.69 | 0.99 | 748.5 | 0.23 |

In the analysis of the results obtained, which were summarised in Table 2, it can be concluded:

1- Phase results (steps): After reading the measurements of No.1 and No.2 from the gas pipeline hermetic system with digital and reflective pressure gauges with 1 hour difference the results showed that the pressure drop is not observed, the strength test is passed and can take No.3 measurement after 24 hours.

When calculating the actual pressure drop at the site after 24 hours, losses amounted to 5.5 mmHg. In the light of all standards, the permissible pressure reduction limit has not been exceeded, the leak check has been passed and the pipeline system can be accepted into service [13].

2- Phase results (steps): The expected gas leak at an installation with a started one flow interruptor after 1 hour and, after all calculations, was composed at 213,54 l/h (formula 5) or 7,078 bar according to pressure gauge figures.
The actual gas leak at an installation with a started one flow interruptor was 60 l/h (formula 5) or 7.11 bar after 1 hour, following pressure gauge parameters – 3.5 times less than expected – 8.4 l*1 bar/h (formula 5) and maximum drilling overflow (according to producers' data) was not achieved. So then: After phase 1 and phase 2, the first hour pressure losses at the installation amount to 0.006 bar – do not exceed the error of the digital manometer measurement. This means that the experiment can be continued with 24 hours of combined tightness testing in phase 2.

In Figure 7, you can see an author's calculation schedule for the loss of gas pipeline pressure with a started one flow interruptor (PV1) after 1 hour of action (bar), where the expected loss of pressure exceeds the measurement error limit by 19 minutes, while the actual loss of pressure at 60 minutes does not reach the measurement error limit.

![Pressure losses in the gas pipeline system with actuated flow rupture (PV1) (bar)](image)

**Figure 7.** Pressure losses in the gas pipeline system with actuated PV1 bar/1h.

Predicted gas leakage at the site after 24 hours and after all calculations was 0.213 m³/h (Formula 5) or 6.58 bar at manometer values. The actual gas leak at the object was 151.25 mmHg or 0.178 bar after 24 hours.

By all standards, the allowed pressure drop limit is exceeded, the leakage check has not been passed, and the pipeline system cannot be accepted into service.

In Figure 8 you can see an author's calculation schedule for the loss of gas pipeline pressure with a started single flow interruptor (PV1) after 24 hours (bar), where the expected loss of pressure exceeds the limit of a measurement error of 3 hours, while the actual pressure loss of 7 to 8 hours reaches the limit of the measurement error. Gas leakage at each hour was 78 l/h (formula 5), 2.7 times less than expected gas leak – 11.25 l*1 bar/h is the maximum drilling overflow.

![Pressure losses in the gas pipeline system with actuated flow rupture (PV1) (bar)](image)

**Figure 8.** Pressure losses in the gas pipeline system with actuated PV1 bar/24h.
3 - Phase results (steps): The expected gas leak at an installation with two flow interruptors activated after 1 hour and, by all calculations, was 426 l/h (formula 5) or 7,065 bar based on manomerts. The actual gas leakage at an installation with two flow interruptors activated was 80 l/h or 7.10 bar after 1 hour, according to pressure gauge figures. Gas leakage 5.3 times lower than expected—11.24 l*1 bar/h and maximum drilling overflow (according to producers’ data) was not achieved. If divided into each rupture, the gas leak through one overflow of the well — 5.62 l*1 bar/h.

By all standards, the allowed pressure drop limit is not exceeded, the leakage check is, passed and the pipeline system can be accepted into service.

Author decides to continue the experiment by performing a 3-phase combined leak test with two flow interruptors engaged for 24 hours.

In Figure 9 you can see an author’s calculation schedule for the loss of gas pipeline pressure with two flow interruptors (PV2) engaged after 1 hour (bar), where the expected loss of pressure exceeds the limit of the measurement error by 10 minutes, while the actual loss of pressure at 53 per minute.

![Figure 9. Pressure losses in the gas pipeline system with actuated PV2 bar/1h.](image)

The expected gas leakage at an installation with two flow interruptors activated after 24 hours and, for all calculations, was 0.415 m³/h or 5.91 bar based on manomerts. The actual gas leak at an installation with two flow stoppers activated was 174 mmHg or 0.228 bar after 24 hours, according to pressure gauge figures. Taking in, too account all standards, the allowed pressure drop limit is exceeded, the leakage check has not been passed, the pipeline system cannot be accepted into service.

In Figure 10, you can see an author’s calculation schedule for the loss of gas pipeline pressure with two flow interruptors (PV2) activated after 24 hours (bar), where the expected loss of pressure exceeds the limit of a measurement error of 1.5 per hour, while the actual loss of pressure of 6.5 per hour reaches the limit of the measurement error.

The gas leak at each hour was 95 l/h, which is 4.4 times less than the expected gas leak – 14.19 l*1 bar/h is the maximum overflow of drills. If divided into each rupture, the gas leakage through one overflow of the well — 7.10 l*1 bar/h.
Conclusion
The results of the experiment:

- By starting one flow interruptor for one hour, the pressure losses of the gas pipeline were in line with the regulatory framework (the potential defect turned into a “Hidden defect”).
- By starting two flow interruptor pressure losses for one hour exceeded the limit value—“Hidden defect” turned into exposed defect.
- By exposing both one and two interruptor for 24 hours, pressure losses exceeded the limit value “Hidden defect” turned into exposed defect.
- Figure 11 concluded that when checking the strength of gas pipeline, leakage (combined inspection) and pressure loss calculations were carried out using the given calculation methodology “Site 2”, pressure losses exceeded the permissible loss limit – the calculation methodology works, defects were found in the pipeline. One the other hand, at “Site 1” (similar to the parameters of the pipeline system), the pressure loses did not exceed the premissible loss limit – no defects were detected in the gas pipeline (erroneous data).

Figure 10. Pressure losses in the gas pipeline system with actuated PV2bar/24.h.

Figure 11. Gas pipeline pressure losses. Object 1(Work) and Objects 2 (Experimental) (mmHg).
The results of the experiment confirmed the non-compliance of the existing calculation methodology and the regulatory base by testing the gas pipeline systems for strength and tightness of gas pipelines with increased and varying diameters, volumes and lengths.

In the Site 1 "Work" a more significant percentage of gas pipeline length and volume is made by the gas pipeline at the building. Calculating mathematically, this fact significantly reduces the average diameter of the total gas pipelines, which affects the calculation of the permissible gas loss limit for the gas pipeline as whole.

The total volume of gas pipeline drives in the Site 2 "Experimental" is smaller and the calculated average diameter of the gas pipeline is close to the actual average diameter of the gas pipeline.

When designing new gas pipelines with an average diameter close to the minimum diameter of the Dn 50mm gas pipelines, the average geometric volume of 9 - 10m³ and the length of 2 - 3 kilometers, it is recommended to test the strength and tightness of the gas pipeline in stages to increase safety criteria.

During the period when the building regulations Latvian Building Code, Latvian National Standard are renewed, it is recommended to increase the stress test time by at least 3 hours.

Continuing further research, calculation methodology and standard improvement requirements to determine more accurate gas pipeline test parameters using author methodology.

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