GAS PIPELINE INCIDENTS

**10th Report of the _E_uropean _G_as Pipeline _I_ncident Data _G_roup
(period 1970 – 2016)**

Comprising:

Gas Networks Ireland (Ireland)
DGC (Denmark)
ENAGAS, S.A. (Spain)
EUSTREAM (Slovak Republic)
Fluxys (Belgium)
Gasum (Finland)
GRT Gaz (France)
National Grid (UK)
Gasunie (Netherlands / Germany)
NET4GAS (Czech Republic)
Gasconnect (Austria)
Open Grid Europe (Germany)
REN Gasodutos S.A. (Portugal)
Snam Rete Gas (Italy)
Swedegas A.B. (Sweden)
SWISSGAS (Switzerland)
TIGF (France)

EGIG

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EGIG encourages the reader, who would like specific information not available in the report, to make direct contact with the companies involved. Company addresses are available on the EGIG website.

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[1] Representing National Grid, Scotia Gas Networks, Wales and the West Utilities and Northern Gas Networks.

CONTENT

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

SUMMARY

In 1982 six European gas transmission system operators took the initiative to gather data on the unintentional releases of gas in their transmission pipeline systems. This cooperation was formalised by the setting up of EGIG (**E**uropean **G**as pipeline **I**ncident data **G**roup). Presently, EGIG is a cooperation of seventeen gas transmission system operators in Europe and it is the owner of an extensive database of pipeline incident data collected since 1970.

The EGIG database is a valuable and reliable source of information that is used to establish pipeline failure frequencies and analyse causes of failures in the gas transmission pipeline systems.

CONCLUSIONS

- The EGIG database is a valuable source of information on European gas pipelines and pipeline incidents.
- EGIG has maintained and expanded the European Gas pipeline incident database. Seventeen gas transmission system operators in Europe now collect incident data on 142,794 km of pipelines every year. The total exposure, which expresses the length of a pipeline and its period of operation, is 4.41 million km·yr.
- In the EGIG database 1,366 pipeline incidents are recorded in the period from 1970-2016.
- The history of incidents collected in the database gives reliable failure frequencies. The overall failure frequency over the period 1970-2016 is equal to 0.31 incidents per year per 1,000 km.
- The five year moving average failure frequency in 2016, which represents the average failure frequency over the past 5 years, equals 0.134 per year per 1,000 km.
- The five year moving average and overall failure frequency have reduced over the years, although it has tended to stabilise over recent years.
- Incidents caused by external interference and ground movement are characterised by potentially severe consequences. This emphasises their importance to pipeline operators and authorities.
- Corrosion as a primary cause has now the same frequency rate as external interference, although consequences are much less severe. Over the last ten years, external interference, corrosion, construction defects and ground movement, represent 28%, 25%, 18% and 15%, respectively of the pipeline incidents reported.

1   INTRODUCTION

The use of pipelines for the transport of large quantities of natural gas to industry and to commercial and domestic consumers represents a reliable mode of transport of energy.

In 1982, six European gas transmission system operators took the initiative to gather data on the unintentional releases of gas in their transmission pipeline systems. This cooperation was formalised by the setting up of EGIG (European Gas pipeline Incident data Group). The objective of this initiative was to provide a broad basis for the calculation of safety performance of pipeline systems in Europe, thus providing a reliable picture of the numbers and frequencies of incidents. Nowadays, EGIG is a cooperation of seventeen gas transmission system operators in Europe and it is the owner of an extensive database of pipeline incident data collected since 1970. The participating companies are now:

Gas Networks Ireland (Ireland)
DGC (Denmark)
ENAGAS, S.A. (Spain)
EUSTREAM (Slovak Republic)
Fluxys (Belgium)
Gasum (Finland)
GRT Gaz (France)
National Grid (UK)[1]
NET4GAS (Czech Republic)
Gasunie (The Netherlands / Germany)
Gasconnect GmbH (Austria)
Open Grid Europe (Germany)
REN Gasodutos S.A. (Portugal)
Snam Rete Gas (Italy)
Swedegas A.B. (Sweden)
SWISSGAS (Switzerland)
TIGF (France)

Considering the number of participants, the extent of the pipeline systems and the exposure period involved, the EGIG database is a valuable source of information on European gas pipelines and pipeline incidents. The results of the database present an average of all participating companies and do not highlight the geographical differences.

Definitions have been used consistently over the entire period. Consequently, provided that the data is correctly used and interpreted, the EGIG database gives useful information about trends which have developed over the years. Nevertheless, particular care must be given to the use and interpretation of the statistical data. The EGIG report gives the failure frequency per design parameter (diameter, pressure, wall thickness) and conclusions about combination of design parameters cannot be drawn.

This report describes the structure of the EGIG database and presents different analyses and their results. The results of the analyses are commented on and give the most interesting information that can be extracted from the database. Linking of results of different analyses is provided where possible. Anyone who would like to combine different results should be very careful before drawing conclusions.

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[1] Representing National Grid, Cadent, Scotia Gas Networks, Wales and the West Utilities and Northern Gas Networks.

2 EGIG DATABASE

The EGIG database is a database for pipeline data and pipeline incident data. Pipeline data and incident data of natural gas transmission pipelines are in the database from 1970 on.

2.1 Objective

The objective of EGIG is to collect and present data on loss of gas incidents in order to present the safety performance of the European gas transmission network to the general public and authorities.

2.2 Criteria

The required criteria for an incident to be recorded in the EGIG database are the following:

- The incident must lead to an unintentional gas release.
- The pipeline must fulfil the following conditions:
    - To be made of steel.
    - To be onshore.
    - To have a Maximum Operating Pressure higher than 15 barg.
    - To be located outside the fences of the gas installations.

Incidents on production lines or involving equipment or components (e.g. valve, compressor) are not recorded in the EGIG database.

2.3 Contents

The EGIG database contains general information about the European gas transmission pipelines system as well as specific information about the incidents.

Every year the length of the pipeline system is collected for the following parameters:

- Diameter
- Pressure
- Year of construction
- Type of coating
- Depth of cover
- Grade of material
- Wall thickness.

Specific information about incidents comprises:

- The characteristics of the pipeline on which the incident happened, namely the general information listed above.
- The leak size:
    - Pinhole/crack: the effective diameter of the hole is smaller than or equal to 2 cm
    - Hole: the effective diameter of the hole is larger than 2 cm and smaller than or equal to the diameter of the pipe
    - Rupture: the effective diameter of the hole is larger than the pipeline diameter.
- The initial cause of the incident
    - External interference
    - Corrosion
    - Construction defect/material failure
    - Hot tap made by error
    - Ground movement
    - Other and unknown.
- The occurrence (or non-occurrence) of ignition.
- The consequences.
- Information on the way the incident has been detected (e.g. contractor, landowner, patrol).
- A free text for extra information.

Additional information is also given for every cause:

- External interference:
    - The activity having caused the incident (e.g. digging, piling, ground works).
    - The equipment involved in the incident (e.g. anchor, bulldozer, excavator, plough).
    - The installed protective measures (e.g. casing, sleeves).
- Corrosion:
    - The location (Internal, External, Unknown).
    - The appearance (General, Pitting, Cracking).
    - In line inspected (yes, no, unknown).
- Construction defect/material failure:
    - The type of defect (construction or material).
    - The defect details (hard spot, lamination, material, field weld or unknown).
    - The pipeline component type (straight, field bend, factory bend).
- Ground movement:
    - The type of ground movement (dike break, erosion, flood, landslide, mining, river or unknown).
- Other and unknown:
    - The sub-causes out of category such as design error, lightning, maintenance error.

This information has been used for the analyses given in this report. EGIG is always considering whether changes in the information would be useful to enhance these analyses.

2.4 Definitions

Failure frequency: The failure frequency is calculated by dividing the number of incidents by the exposure. The EGIG report presents two kinds of failure frequencies, the **primary** and the **secondary**. They refer to the notions of total and partial exposure respectively. These notions are defined below.

- Exposure is the length of a pipeline multiplied by its exposed duration and is expressed in kilometres-years [km·yr]. Example: a company has a constant length of transmission pipelines over 5 years of 1,000 km. Its exposure is then 5 times 1,000 km, so 5,000 km·yr.
- The total system exposure is the exposure as defined above, calculated for the complete system.
- The partial system exposures are the exposures calculated per class of a certain design parameter, e.g. per diameter class or per depth of cover class.

Five year moving average: In order to illustrate trends, a five year moving average has been introduced. The five year moving average for the year in question means that the calculations have been performed over the 5 previous years.

Confidence interval: A confidence interval gives an estimated range of values which is likely to include an unknown population parameter, the estimated range being calculated from a given set of sample data. In this report, a confidence interval of 95% is calculated for the failure frequencies.

2.5   The use of EGIG data

The objective of the EGIG group is to show the incident data of gas transmission pipelines, registered by a European group of operators which in general follow similar design, construction, inspection and maintenance practices.

Within EGIG, all data collected, reported and analysed is data of the group as a whole and no distinction can and will be made per operator.

EGIG publishes statistics over different time intervals. In this report, the statistics of the whole database (covering the period 1970-2016), but also the most important statistics over the last 40, 30, 20, 10 and 5 years are reported. It must be noted that given the theory of statistics, the confidence interval of the mean values of the failure frequencies over five years is larger than for a longer period (for instance 20 years). The user of EGIG data must consider the statistical reliability of the data when deciding how it is to be used (see also APPENDIX 2).

Graphs
Some of the graphs presented in this report will cover the whole period of the EGIG database (1970-2016). To demonstrate developments and trends over more recent periods, the EGIG report also shows graphs that cover the last ten years (2007-2016) or represent the five year moving average.

The report aims to interpret the information contained in the data in order to draw conclusions from the sample or the population from which the sample is taken. The statistical analyses are based on the calculation of indicators such as failure frequency and the percentage of the releases that ignited.

The EGIG database offers an overview of the failure frequencies of the European gas transmission pipelines system. It gives information on the failure frequencies in relation to one pipeline parameter (e.g. diameter, pressure, wall thickness), but does in general not offer the possibility of making correlation analyses. For example, with the EGIG database it is possible to establish the failure frequency of ≥42-inch pipelines or to establish the failure frequency of pipelines with a wall thickness of >15 mm, but it is not possible to calculate the failure frequency of ≥42-inch pipelines with a wall thickness of >15 mm.

3   ANALYSES AND RESULTS

3.1   Trends gas transmission system

This paragraph gives information on the trends in the European gas transmission system. It not only shows the evolution of the exposure, but also which design characteristics tend to be more or less used in today's construction. This paragraph gives a picture of the European gas transmission system from 1970 up to the present.

3.1.1   Total length

The total length of the European gas transmission pipelines system in EGIG has remained at approximately the same level since the last six years. The evolution of the total length of the system is shown in Figure 1 and is also given per class in Figure 2 to Figure 8 for several pipeline parameters (diameter, pressure, etc.).
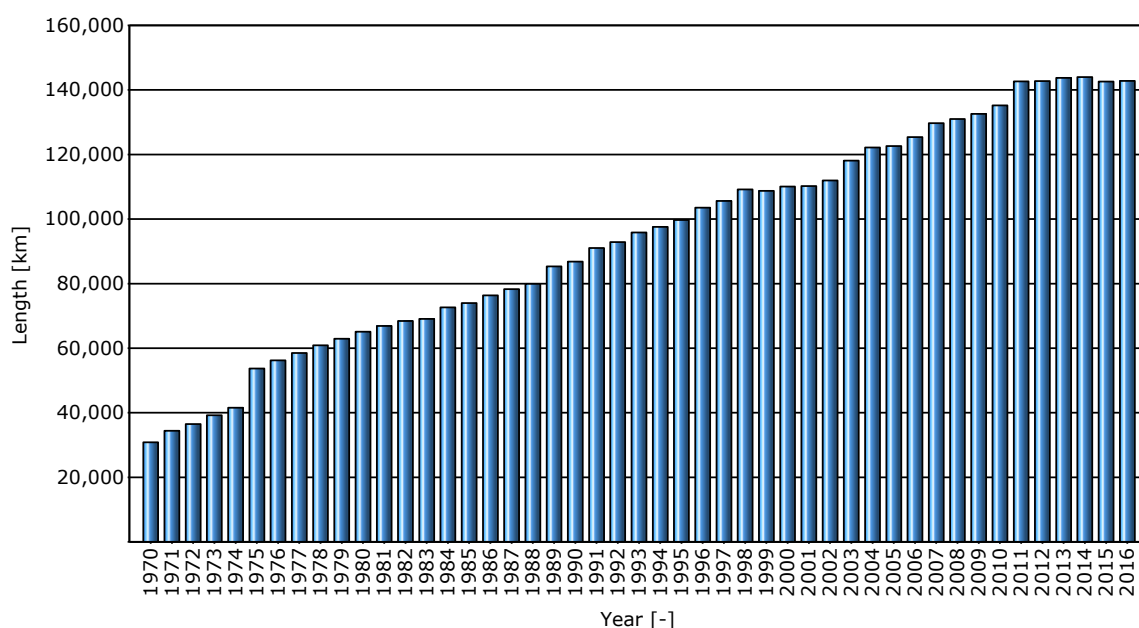
Figure 1: Total length of the European gas transmission system in EGIG

Figure 1 shows the increase in the length of the European gas transmission system in EGIG, which has significant step changes in the years 1975, 1989, 1991, 1998, 2003 and 2007 and 2011. These changes correspond to (data of) new members joining EGIG. The pipeline length stabilizes from the year 2011.
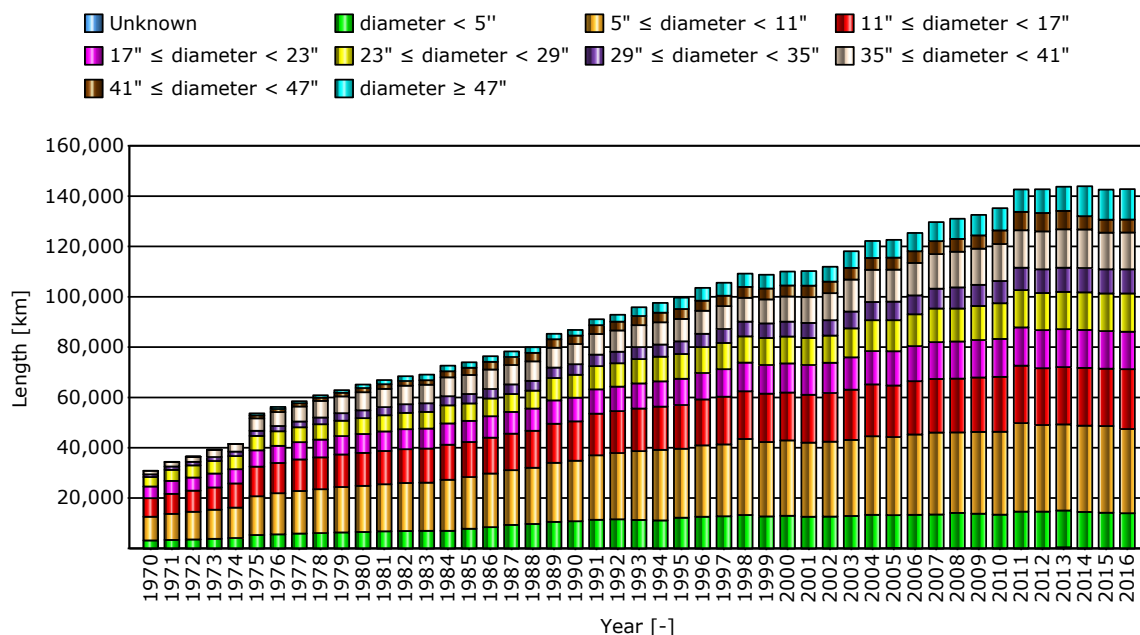
Figure 2: Total length per diameter

Figure 2 demonstrates that the 5''≤diameter<11'' and the 11''≤diameter<17'' classes are still the most commonly used.
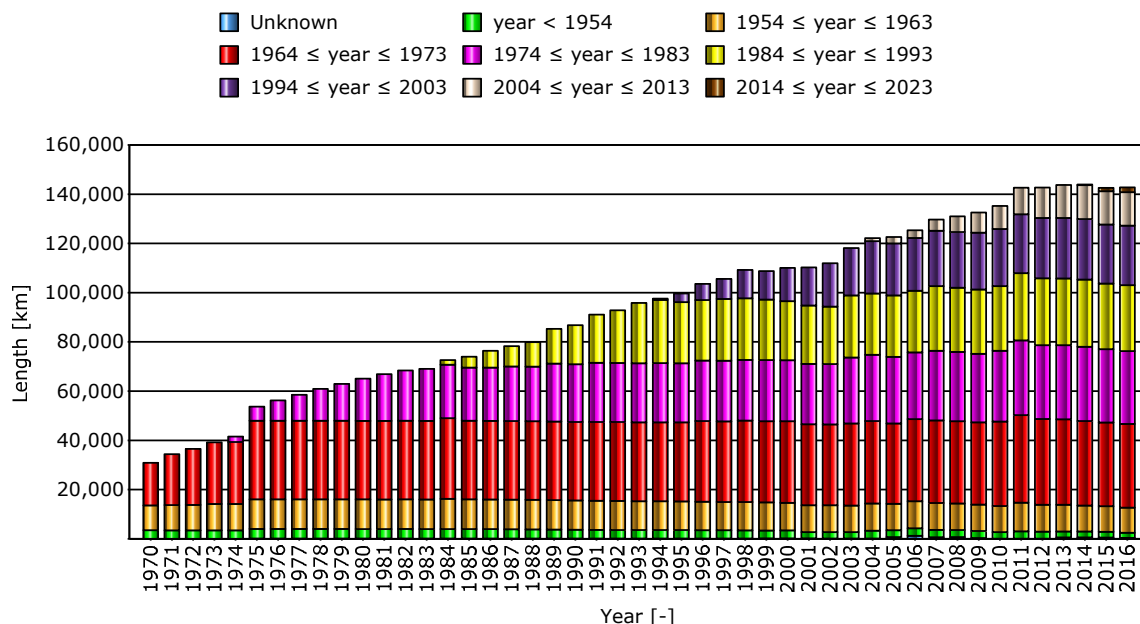
Figure 3: Total length per year of construction

Figure 3 shows that more pipelines were built in the period 1964-1973 than in other periods. No significant drop can be observed, which means that most of these pipelines are still in operation. Also new pipelines continue to be constructed.
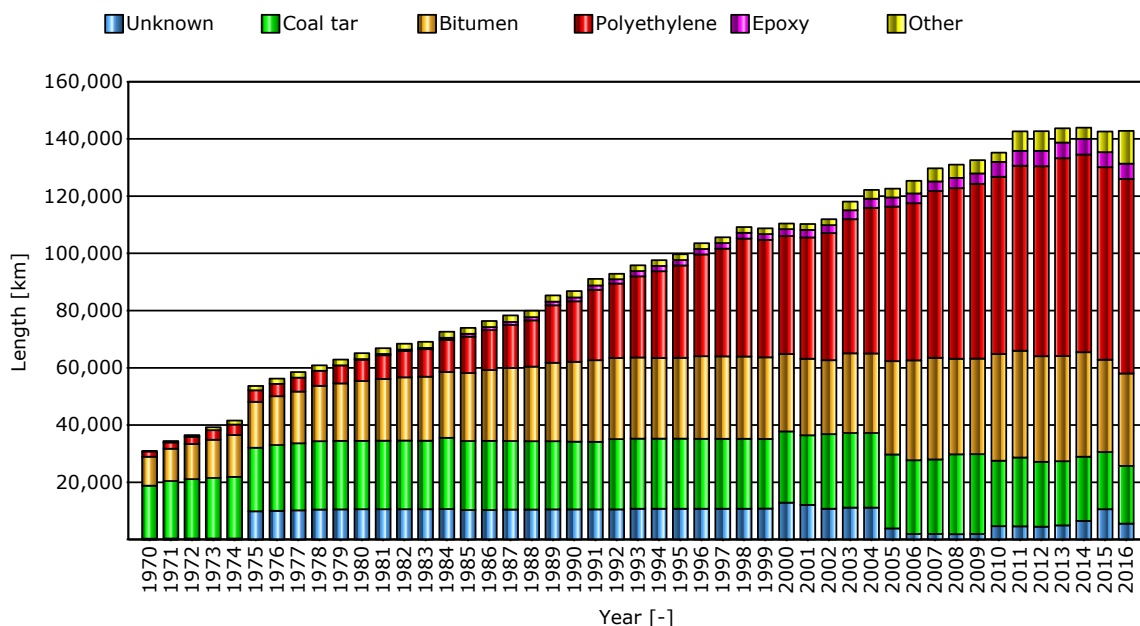
Figure 4: Total length per type of coating

Figure 4 shows that coal tar, bitumen and polyethylene are the most common coatings in the database, with a clear predominance of the last one. In the most recent decades the vast majority of new pipelines have been coated with polyethylene.
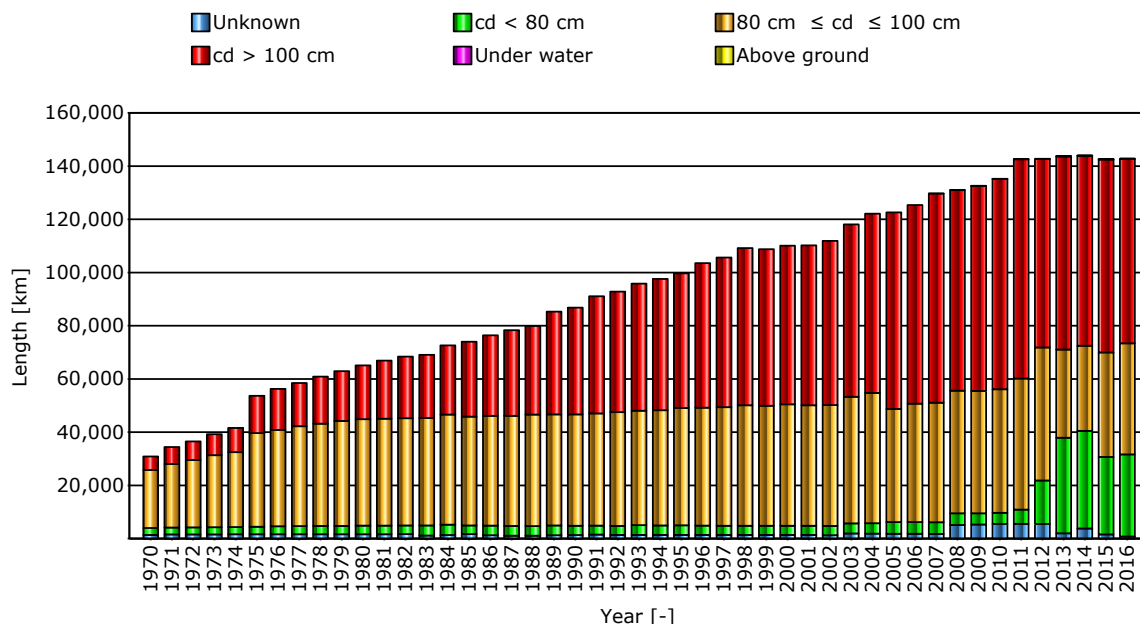
Figure 5: Total length per depth of cover (cd)

Figure 5 shows that the vast majority of the pipelines have a depth of cover greater than 80 cm.

Most companies and design codes recognise depth of cover as an important factor in reducing exposure to external interference. The figure shows an increase over time of the pipeline length with a depth of cover greater than 1 meter.
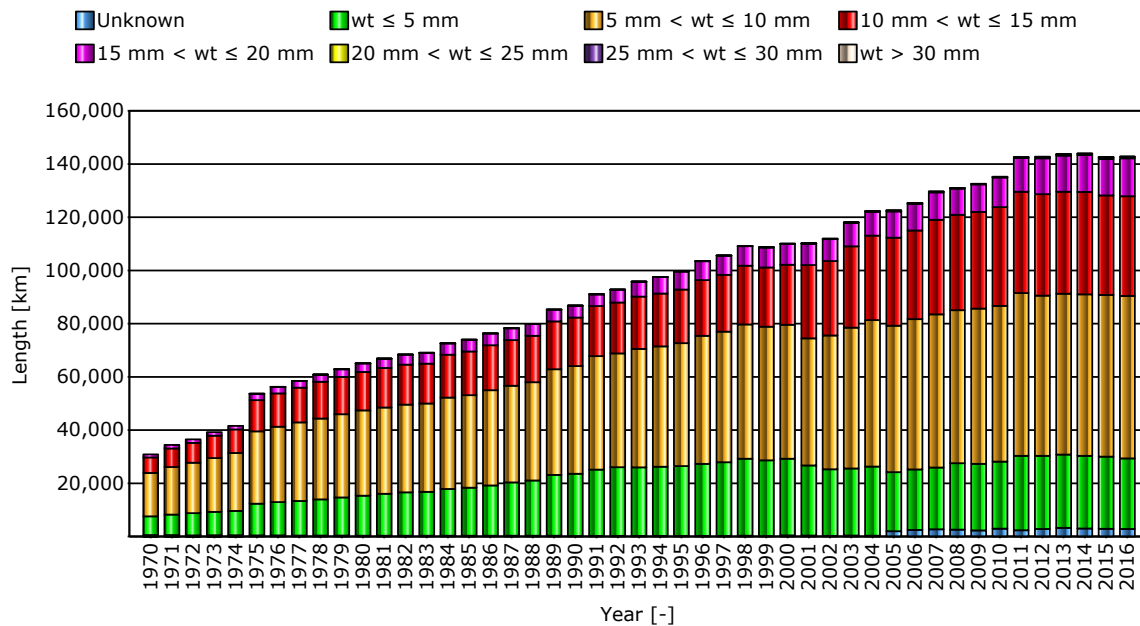
Figure 6: Total length per wall thickness (wt)

Figure 6 shows that the most commonly used pipeline wall thicknesses are 5 to 10 mm. The figure also shows that the pipeline length for every wall thickness class increases constantly over time except for the ≤ 5 mm class, which has remained more or less constant in length since 2001.
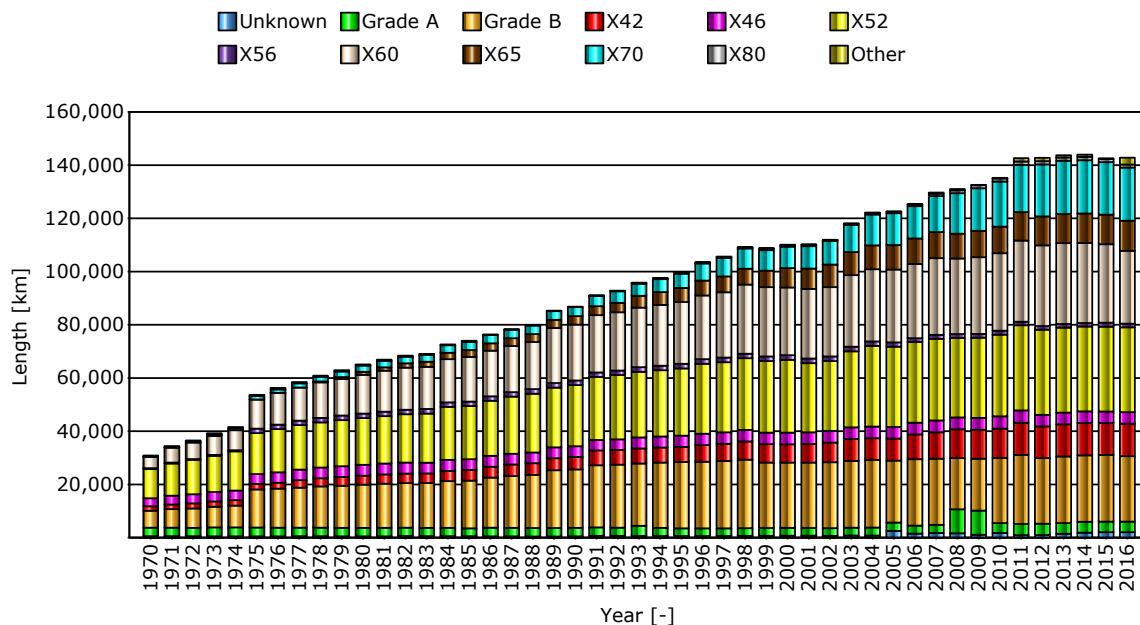
Figure 7: Total length per grade of material

Line pipe grade designations come from different specifications. The EGIG database is arranged according to equivalent API 5L grades, i.e. line pipe can have grade A, B or a higher grade with designation X followed by a number specifying the yield strength (in pounds per square inch) of the pipe steel. Grade A is used for older pipelines. Grade B is still used for new pipelines, especially for pipelines with relative small diameters.

Figure 7 demonstrates that three grades of material are predominant, namely: Grade B, X52 and X60.
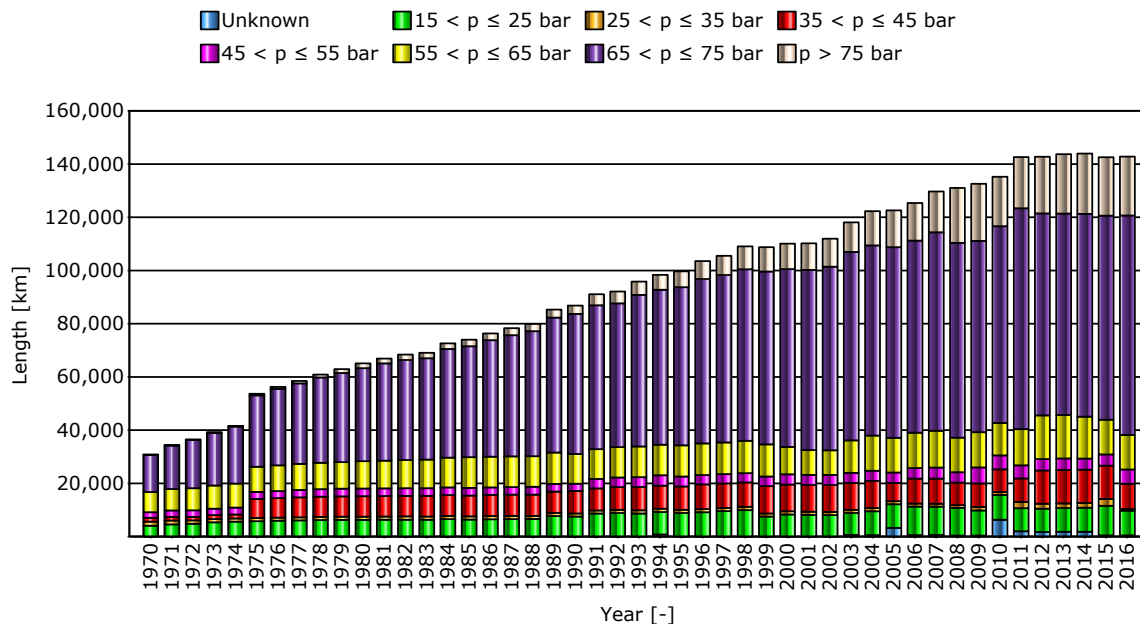
Figure 8: Total length per Maximum Operating Pressure (p)

Figure 8 shows a predominance of Maximum Operating Pressure of 65 bar and higher.

3.1.2 Exposure

Figure 9 shows the increase of the exposure over the years. As discussed in paragraph 2.4, exposure is the length of a pipeline multiplied by its exposed duration and is expressed in kilometres-years [km·yr]. In 2016, the total system exposure was equal to 4.41 million km·yr. Figure 10 shows the average age of the pipeline system over the years.
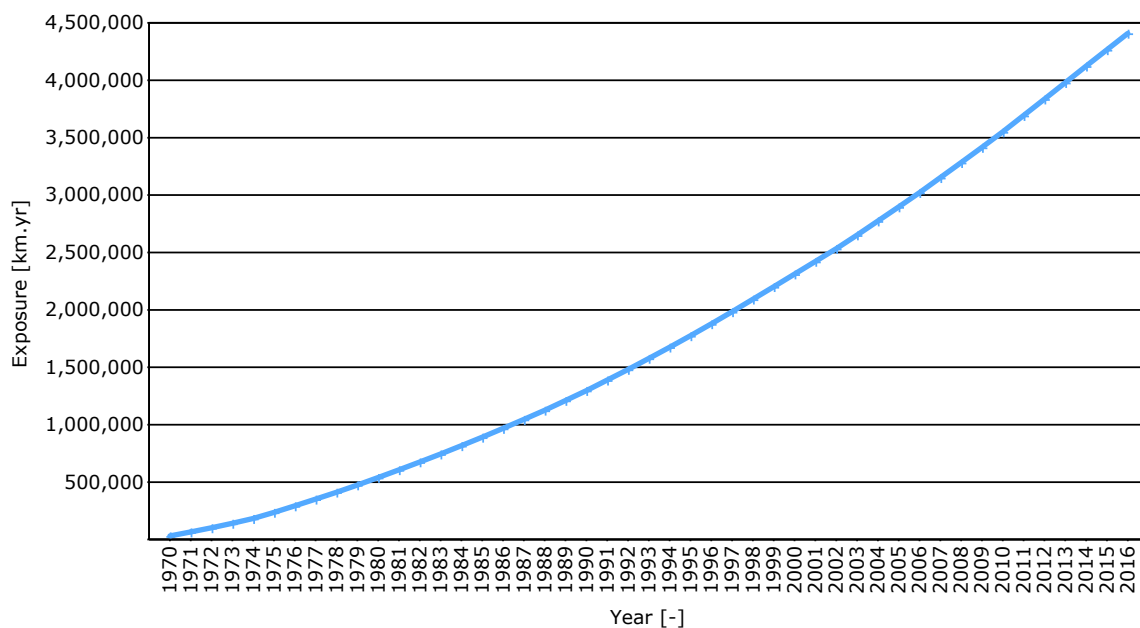
Figure 9: Evolution of the exposure
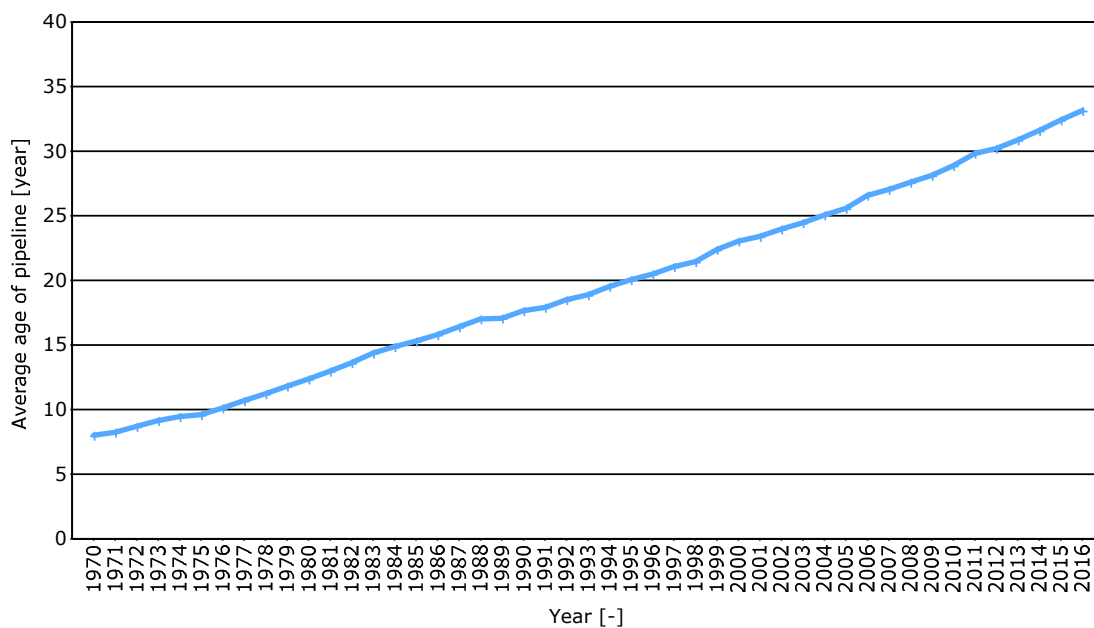
Figure 10: Average age of the pipeline system

3.2 Trends of the number of incidents

In the ninth EGIG report, which covers the period 1970-2013, a total of 1,310 incidents were recorded. In the last three years, 56 incidents were reported by the EGIG members, which brings the total number of incidents to 1,366 for the period 1970-2016. Figure 11 shows the number of incidents per year. Figure 12 shows the cumulative number of incidents.
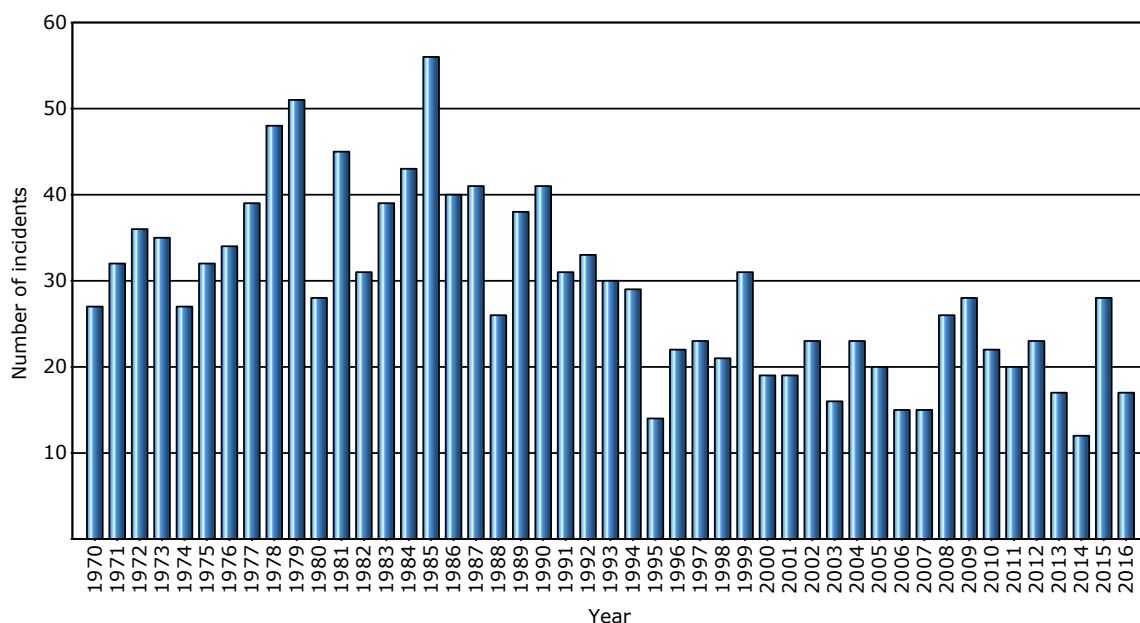
Figure 11: Number of incidents per year
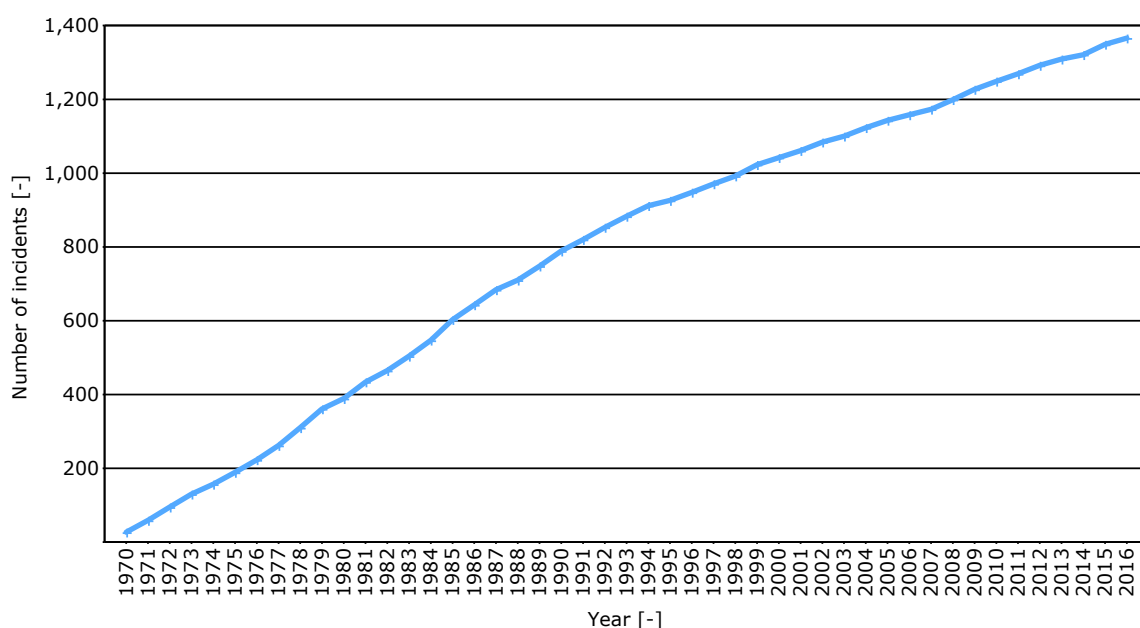
Figure 12: Cumulative number of incidents

3.3 Failure frequencies analyses

This paragraph deals with the calculation of safety indicators, namely the primary and secondary failure frequencies.

3.3.1 Primary failure frequencies

As explained in paragraph 2.4, the primary failure frequency is the result of the number of incidents (Figure 12) within a period divided by the corresponding total system exposure (Figure 9). Depending on the period considered, the number of incidents varies and so does the total system exposure.

EGIG has compared the primary failure frequencies of different periods, namely the total period (1970-2016), periods corresponding to the previous EGIG reports and of periods of the last 40, 30, 20, 10 and 5 years.

The primary failure frequencies of these periods are given in Table 1. The 95% confidence limits of the failure frequencies of these periods are given in APPENDIX 1. For the statistical analysis the assumption is made that the number of incidents follows Poisson's law (see APPENDIX 2).

Period	Interval	Number of incidents	Total system exposure $\cdot 10^6$ km·yr	Primary failure frequency per 1,000 km·yr
1970 – 2007	7th report, 38 years	1,173	3.15	0.372
1970 – 2010	8th report, 41 years	1,249	3.55	0.351
1970 – 2013	9th report, 44 years	1,309	3.98	0.329
1970 – 2016	10th report, 47 years	1,366	4.41	0.310
1977 - 2016	40 years	1,143	4.12	0.278
1987 - 2016	30 years	723	3.44	0.210
1997 - 2016	20 years	418	2.53	0.165
2007 - 2016	10 years	208	1.39	0.150
2012 - 2016	5 years	97	0.72	0.136

Table 1: Primary failure frequencies

In 2016, the primary failure frequency over the entire period (1970-2016) was equal to 0.31 per 1,000 km·yr. This is slightly lower than the failure frequency of 0.33 per 1,000 km·yr reported in the 9th EGIG report (1970-2013).

The primary failure frequency over the last five years was equal to 0.14 per 1,000 km·yr, showing an improved performance over recent years.

Figure 13 illustrates the steady drop of the primary failure frequencies. The primary failure frequency over the entire period decreased from 0.87 per 1,000 km·yr in 1970 to 0.31 per 1,000 km·yr in 2016. The five year moving average primary failure frequency decreased by a factor 6 (0.86 to 0.14 per 1,000 km·yr).
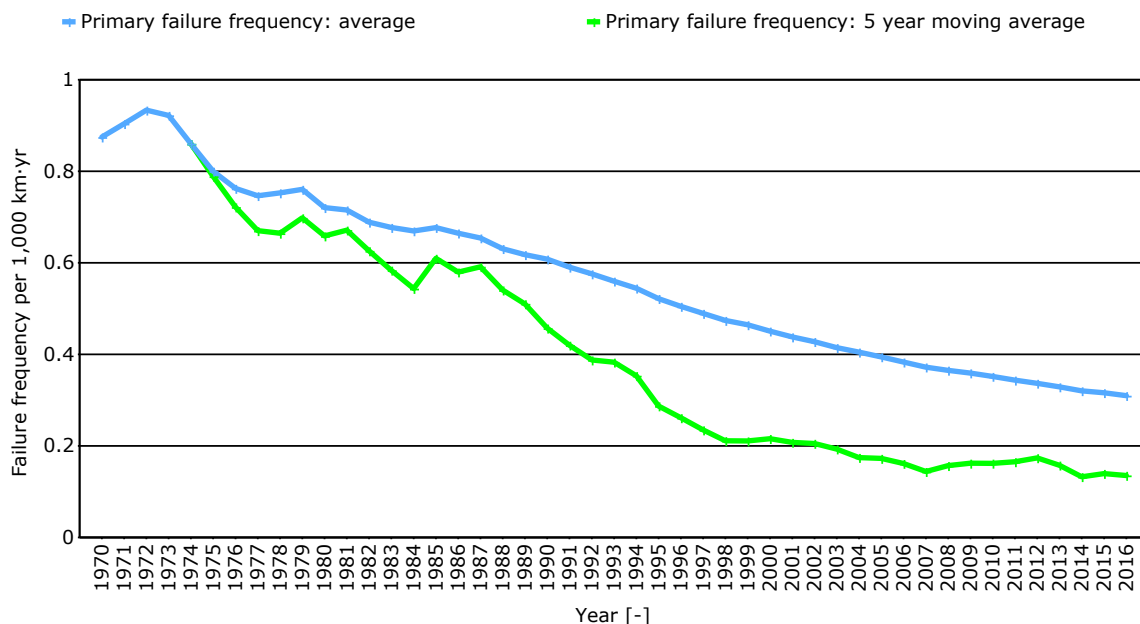
Figure 13: Primary failure frequencies

Not all leaks result in severe consequences. The EGIG database distinguishes between incidents with different leak size (ruptures, holes and pinholes/cracks). Figure 14 demonstrates the five year moving average failure frequency per leak size.
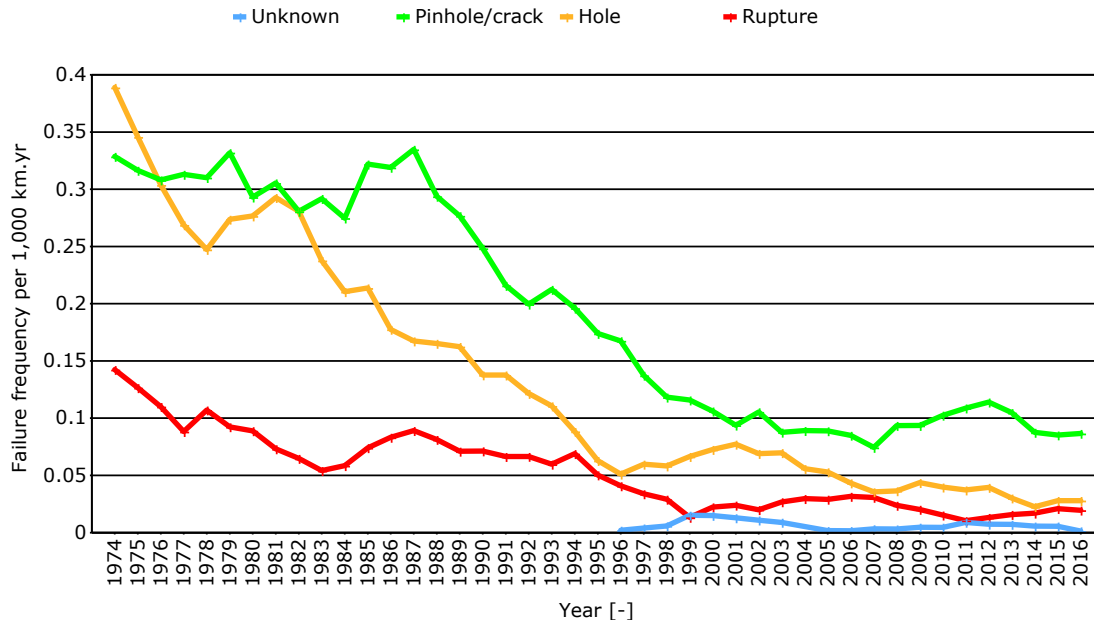
Figure 14: Primary (5-year moving) failure frequency per leak size

Figure 14 shows that the failure frequencies for holes and ruptures are smaller than the failure frequencies for pinhole/cracks. Also a decrease over the years of the 5-year moving average can be seen for all leak sizes. From the year 2000 on this trend seems to stabilise. For the year 2016 these values are given in Table 2.

Leak size	Primary 5 year mov. failure frequency per 1,000 km·yr
Unknown	0.001
Pinhole/crack	0.087
Hole	0.028
Rupture	0.020

Table 2: Primary 5-year moving failure frequency per leak size in 2016

In Figure 15, the incident distribution per cause over the last 10 years is given. Corrosion and external interference incidents occurred in about the same rate. However, corrosion incidents tend to have smaller leak sizes (see Figure 17 and Figure 18).
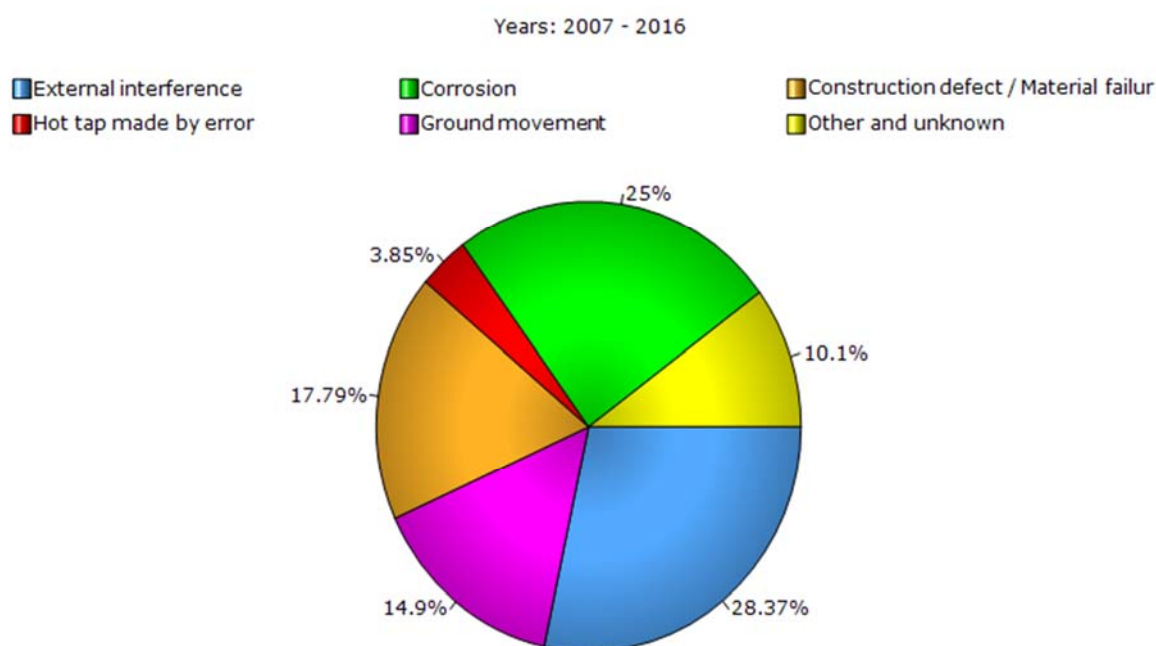
Figure 15: Distribution of incidents (2007–2016)

Figure 16 illustrates the decreasing failure frequencies per cause over the years. The decrease may be explained by technological developments, such as: welding, inspection, condition monitoring using in-line inspection and improved procedures for damage prevention and detection. Improvements in the prevention of external interference incidents may be explained by a more stringent enforcement of land use planning and the application of one-call systems for the digging activities of external parties. In several countries, there is now a legal requirement to report digging activities. Companies have adopted appropriate actions, like supervision or marking of the pipeline in the direct neighbourhood of the digging activities.
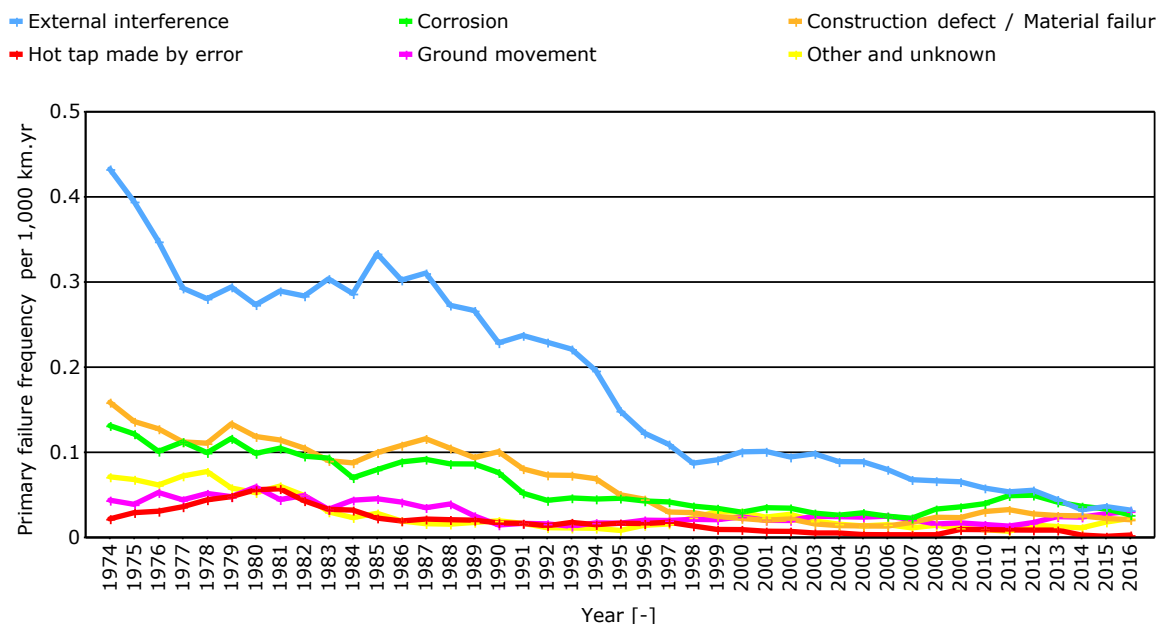
Figure 16: Primary failure frequencies per cause (5-year moving average)

Cause	Primary failure frequency			
	1970-2016 per 1,000 km·yr	1997-2016 per 1,000 km·yr	2007-2016 per 1,000 km·yr	2012-2016 per 1,000 km·yr
External interference	0.144	0.064	0.043	0.032
Corrosion	0.052	0.034	0.037	0.027
Construction defect / Material failure	0.051	0.022	0.027	0.021
Hot tap made by error	0.014	0.006	0.006	0.003
Ground movement	0.026	0.023	0.022	0.031

Table 3: Primary failure frequencies per cause (confidence intervals are given in APPENDIX 1)

To demonstrate failure frequencies over a more recent period, Table 3 also presents, in addition to the frequencies for the whole period, frequencies over a time span of the last 5, 10 and 20 years. As far as the cause external interference is concerned, its associated primary failure frequency over the five year moving average has levelled off at around 0.03 per 1,000 km·yr.

Figure 17 (period 1970-2016), Figure 18 (period 2007-2016) and Table 4 show the failure frequency per leak size and per incident cause. Although the failure frequency decreased over the years, the general trend in the distribution of the leak sizes remain the same: holes and ruptures were mainly caused by external interference. For pinhole/crack leak sizes, corrosion remains the main cause.

Figure 17 and Figure 18 show that corrosion in the vast majority of incidents has led to pinhole/crack type of leak. Very few holes were observed and only one rupture occurred on a pipeline. This rupture, on a pipeline constructed before 1954, was caused by internal corrosion of a pipeline originally used for the transportation of coke oven gas and is not representative for normal corrosion incidents.
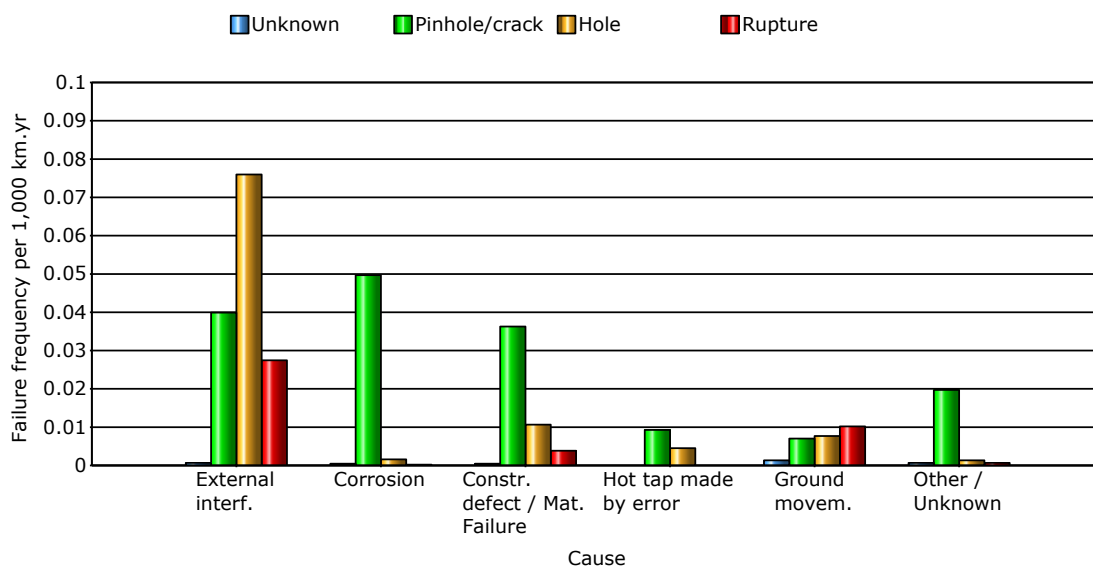
Figure 17: Relationship primary failure frequency, cause and size of leak (1970-2016)

Years: 2007 - 2016
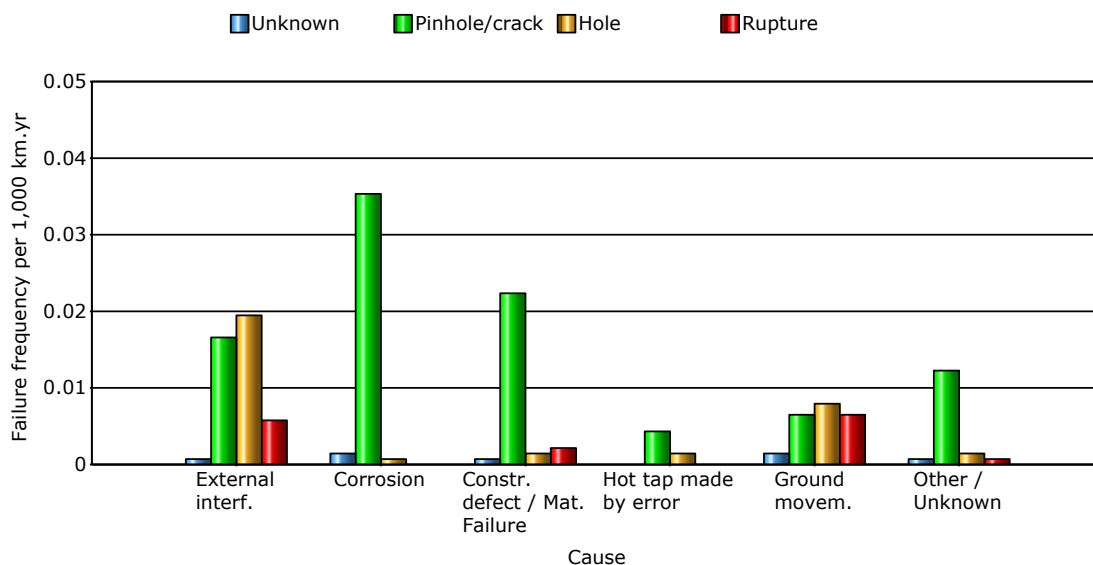
Figure 18: Relationship primary failure frequency, cause and size of leak (2007-2016)

Leak size	Failure frequency per 1,000 km·year					
	External interference	Corrosion	Construction defect / Mat. Failure	Hot tap made by error	Ground movement	Other and unknown
Rupture	0.0058	0.0000	0.0022	0.0000	0.0065	0.0007
Hole	0.0195	0.0007	0.0014	0.0014	0.0079	0.0014
Pinhole/crack	0.0166	0.0353	0.0224	0.0043	0.0065	0.0123
Unknown	0.0007	0.0014	0.0007	0.0000	0.0014	0.0007

Table 4: Primary failure frequency, cause and size of leak (2007-2016)

3.3.2 *Secondary failure frequencies*

The secondary failure frequencies are calculated by dividing the number of incidents by a partial system exposure. Partial system exposure means, for example, the exposure related to one diameter class or one year of construction class.

The calculation of secondary failure frequencies is done to consider the influence of design parameters (pressure, diameter, depth of cover, etc.) on the failure frequencies per incident cause and per type of leak size. The calculations are performed for the whole database and for a more recent time period of the last 10 years (2007-2016).

For six incident causes, the secondary failure frequencies have been calculated according to the following design parameters:

- External interference: the diameter of the pipeline, the depth of cover and the wall thickness.
- Corrosion: the year of construction, the type of coating and the wall thickness.
- Construction defect/material failure: the year of construction.
- Hot tap made by error: the diameter of the pipeline.
- Ground movement: the diameter of the pipeline.
- Other and unknown: main causes.

For "Ground movement" and "other and unknown" causes other more relevant considerations are reported.

3.3.2.1 *Relationship between diameter class and size of leak*

Table 5 and Table 6 demonstrate the relationship between the secondary failure frequency, the leak size and diameter of the pipeline. The secondary frequencies are given for a time period of 10 and 20 years as this is considered more representative for the current operating practises than taking the whole period.

Figure 19: Secondary failure frequency, pipeline diameter and size of leak (1997-2016)

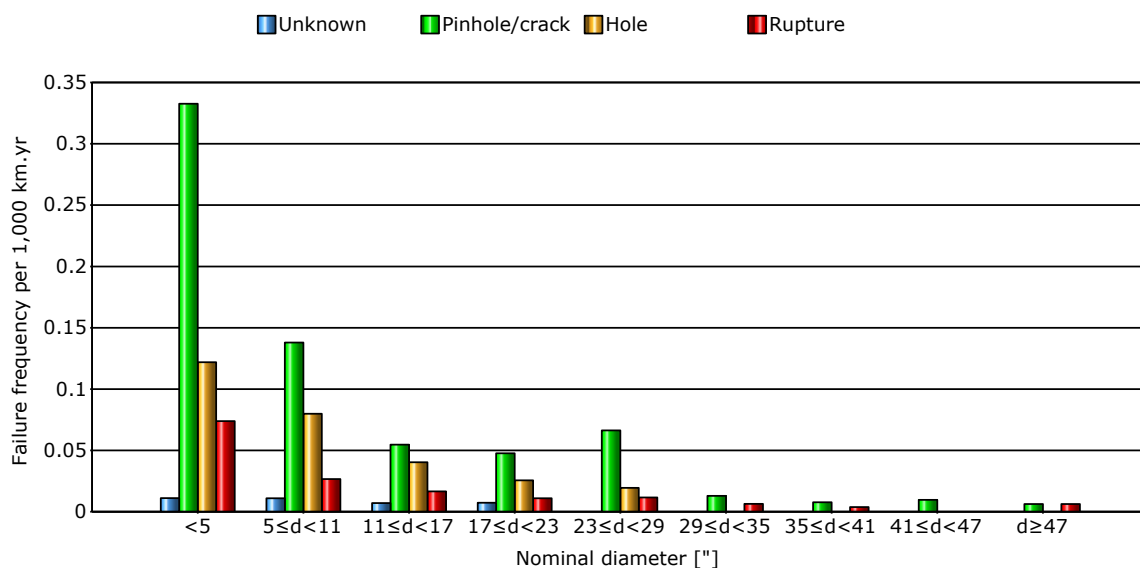| Nominal diameter	System exposure ·10^6 km·yr	Secondary failure frequency per 1,000 km·yr			
		Unknown	Pinhole/crack	Hole	Rupture
diameter < 5''	0.271	0.011	0.333	0.122	0.074
5" ≤ diameter < 11"	0.638	0.011	0.138	0.080	0.027
11" ≤ diameter < 17"	0.421	0.007	0.055	0.040	0.017
17" ≤ diameter < 23"	0.273	0.007	0.048	0.026	0.011
23" ≤ diameter < 29"	0.256	0.000	0.066	0.020	0.012
29" ≤ diameter < 35"	0.154	0.000	0.013	0.000	0.006
35" ≤ diameter < 41"	0.257	0.000	0.008	0.000	0.004
41" ≤ diameter < 47"	0.103	0.000	0.010	0.000	0.000
diameter ≥ 47"	0.157	0.000	0.006	0.000	0.006

Table 5: Secondary failure frequency, pipeline diameter and size of leak (1997-2016)

Nominal diameter	System exposure ·10^6 km·yr	Secondary failure frequency per 1,000 km·yr			
		Unknown	Pinhole/crack	Hole	Rupture
diameter < 5"	0.141	0.014	0.376	0.071	0.057
5" ≤ diameter < 11"	0.336	0.006	0.134	0.060	0.018
11" ≤ diameter < 17"	0.224	0.009	0.054	0.040	0.013
17" ≤ diameter < 23"	0.150	0.007	0.053	0.020	0.000
23" ≤ diameter < 29"	0.144	0.000	0.084	0.021	0.021
29" ≤ diameter < 35"	0.090	0.000	0.022	0.000	0.011
35" ≤ diameter < 41"	0.147	0.000	0.007	0.000	0.000
41" ≤ diameter < 47"	0.058	0.000	0.017	0.000	0.000
diameter ≥ 47"	0.096	0.000	0.010	0.000	0.000

Table 6: Secondary failure frequency, pipeline diameter and size of leak (2007-2016)

Figure 19, Table 4, Table 5 and Table 6 illustrate that ruptures mainly occurred at pipelines with smaller diameters and that failure frequencies decrease with increasing diameter.

3.3.2.2 Relationship between external interference, size of leak and design parameter

Figure 20 to Figure 25 show the failure frequencies for the incident cause "external interference" for different pipeline design parameter classes and leak sizes. The design parameters considered are: pipeline diameter, depth of cover and wall thickness. For the design parameters diameter and wall thickness the graphs are presented for both the whole period 1970-2016 and the last ten years (2007-2016). For depth of cover a graph is presented for the period 1970-2016 and a graph is presented with the development of the 5 year moving average failure frequency per depth of cover. Although the graphs are presented separately, it must be noticed that the design parameters are correlated. No quantitative correlations between parameters have been studied.
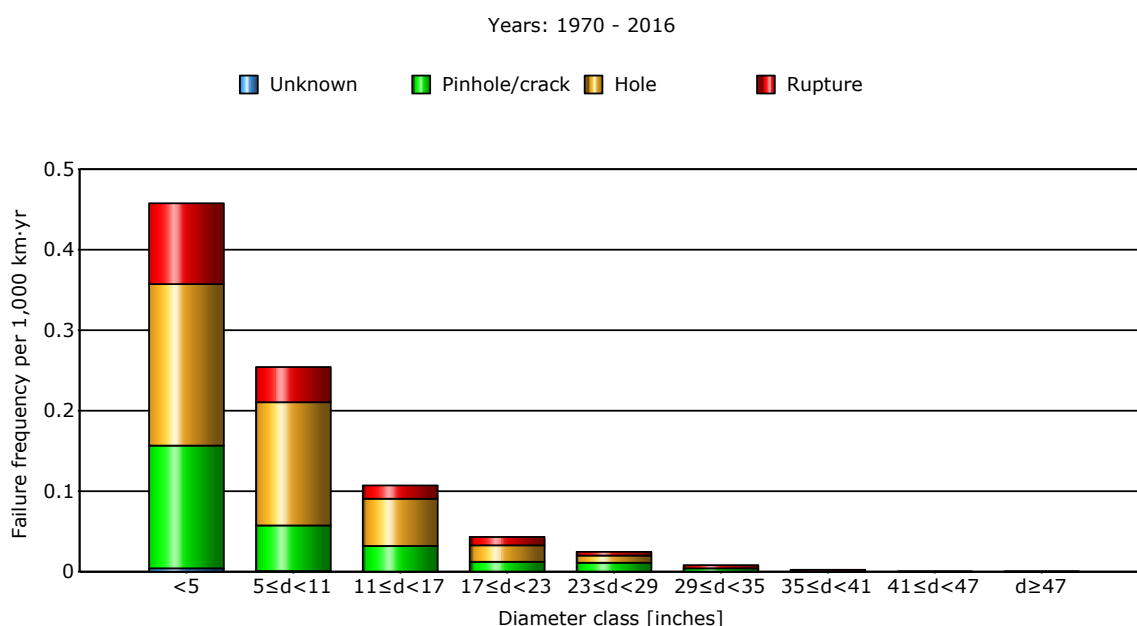
Figure 20: Relationship external interference, leak size and diameter (d) (1970-2016)

Years: 2007 - 2016
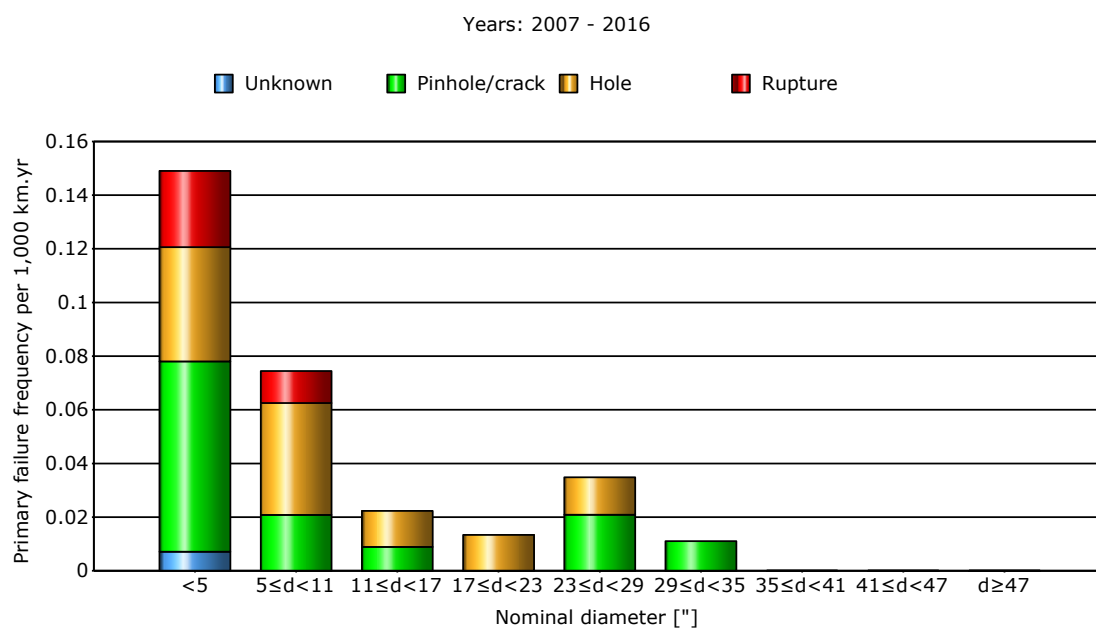
Figure 21: Relationship external interference, leak size and diameter (d) (2007-2016)
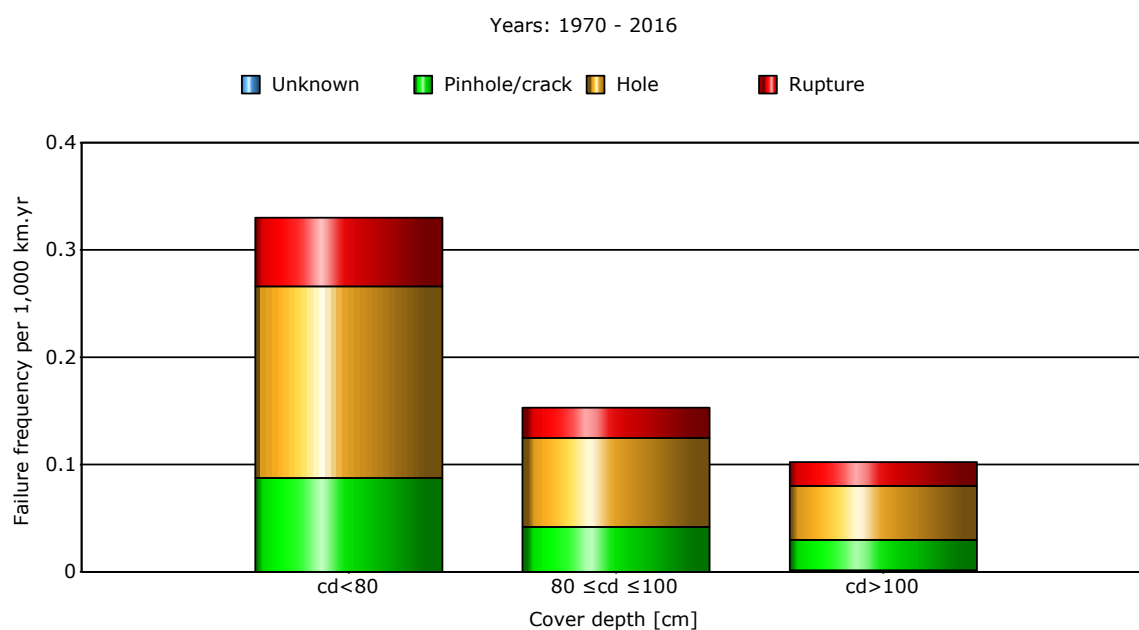
Years: 1970 - 2016

Figure 22: Relationship external interference, leak size and depth of cover (cd) (1970-2016)
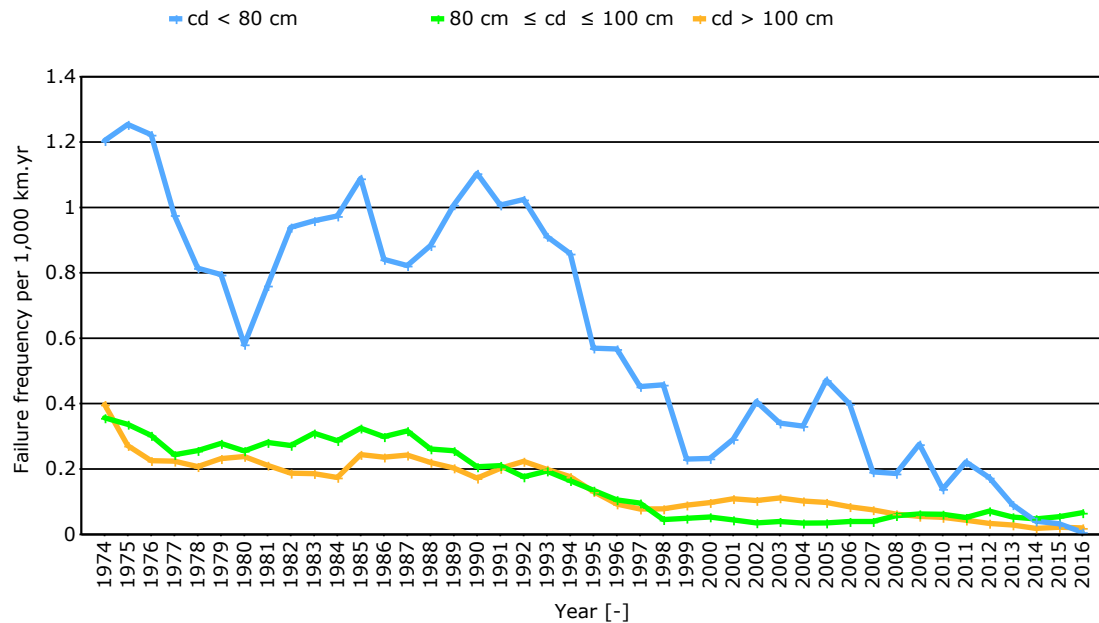
Figure 23: Relationship between external interference and depth of cover (cd) 5 year moving average.
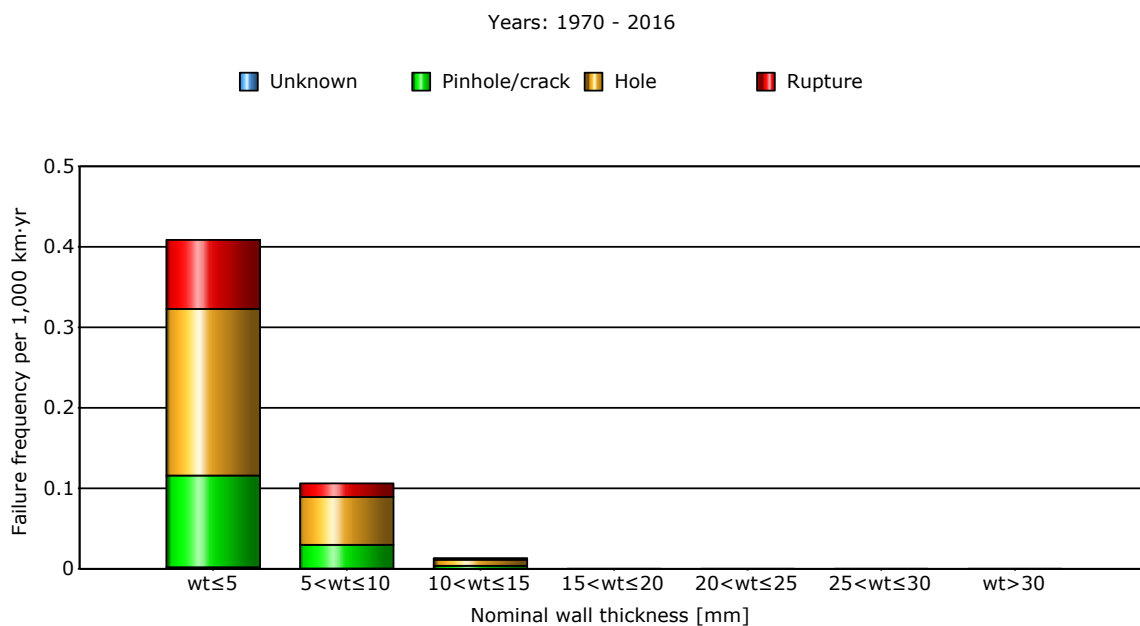
Years: 1970 - 2016

Figure 24: Relationship external interference, leak size and wall thickness (wt) (1970-2016)

Years: 2007 - 2016
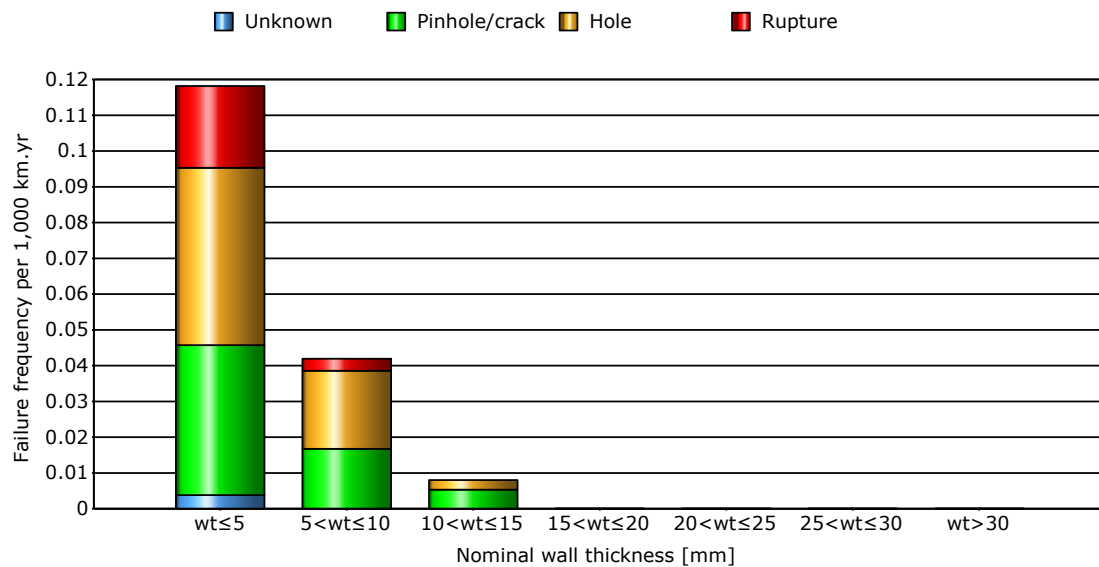
Figure 25 : Relationship external interference, size of leak and wall thickness (wt) (2007-2016)

From these figures, some general conclusions can be drawn:

- Large diameter pipelines are less vulnerable to external interferences than smaller diameter pipelines (Figure 20 and Figure 21). There might be several explanations for this: small diameter pipelines can be more easily hooked up during ground works than bigger pipelines, their resistance is often lower due to thinner wall thickness and they might be found more frequently in urban areas where third party activity is generally higher.
- The depth of cover is one of the leading indicators for the failure frequencies of pipelines. Pipelines with a larger depth of cover have a lower failure frequency. This can be seen from Figure 22.
- Figure 23 shows that the external interference failure frequencies of all depth of cover classes have decreased over the years.
- Pipelines with a larger wall thickness have a lower failure frequency for external interference (Figure 24 and Figure 25).
- No External Interference incidents occurred with wall thicknesses above 15 mm.

3.3.2.3 *Relationship between corrosion, size of leak and design parameter*

Figure 26 to Figure 31 show the failure frequencies for the incident cause "corrosion" for different pipeline parameter classes and leak sizes. The parameters considered are year of construction, type of coating and wall thickness. For each design parameter two graphs are constructed: one for the period 1970-2016 and one for the period 2007-2016.
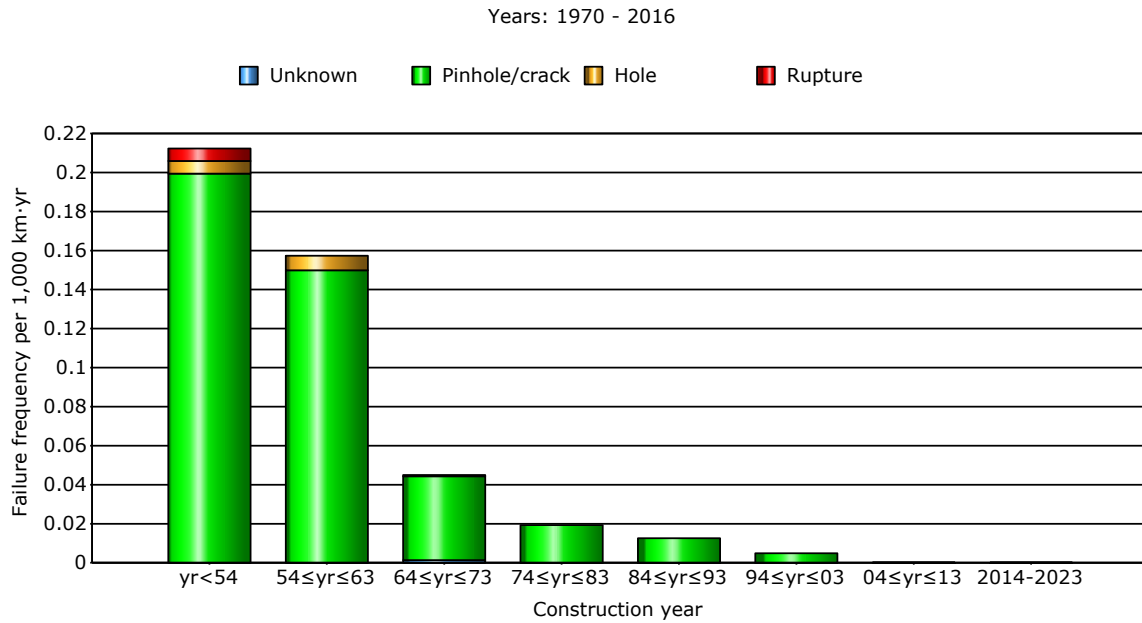
Years: 1970 - 2016

Figure 26: Relationship corrosion, size of leak and year of construction (1970-2016)
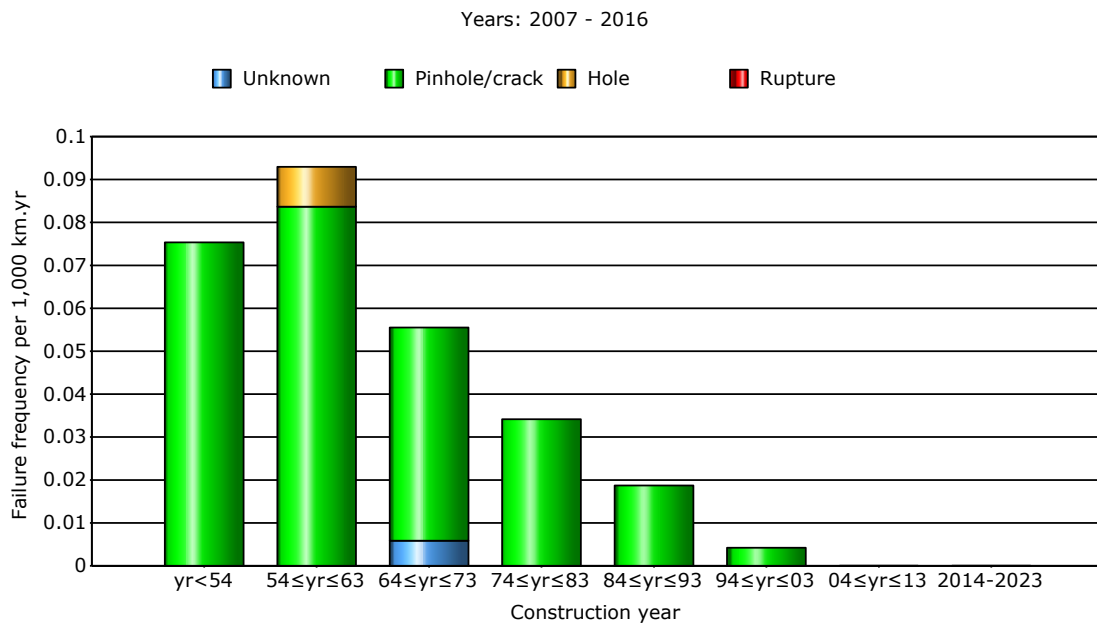
Years: 2007 - 2016

Figure 27: Relationship corrosion, size of leak and year of construction (2007-2016)
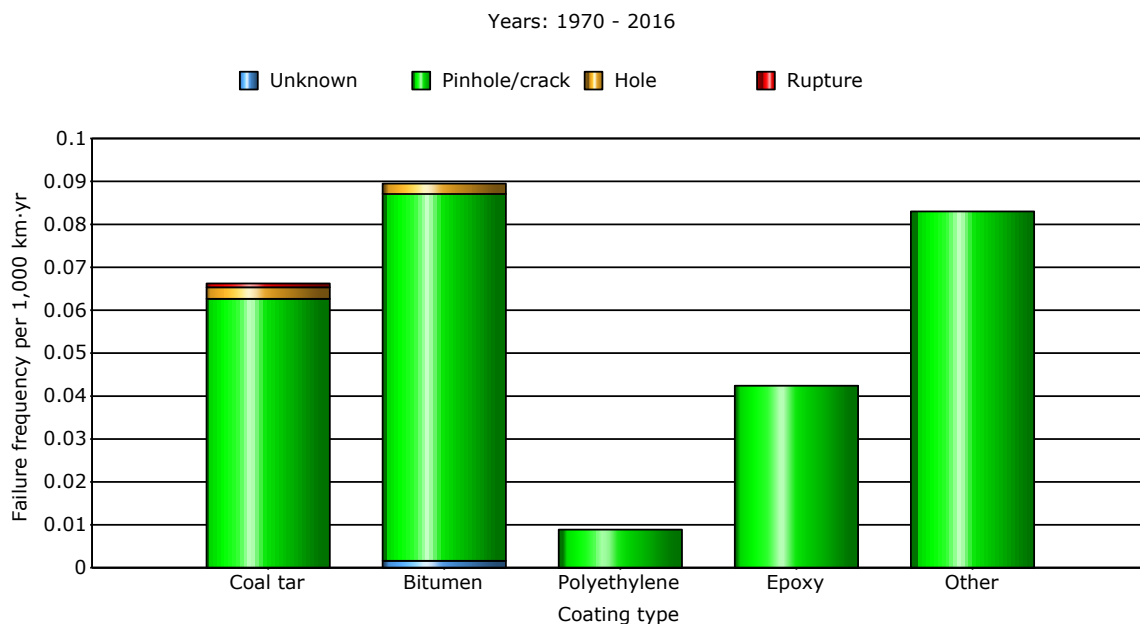
Years: 1970 - 2016

Figure 28: Relationship corrosion, size of leak and most common type of coating (1970-2016)
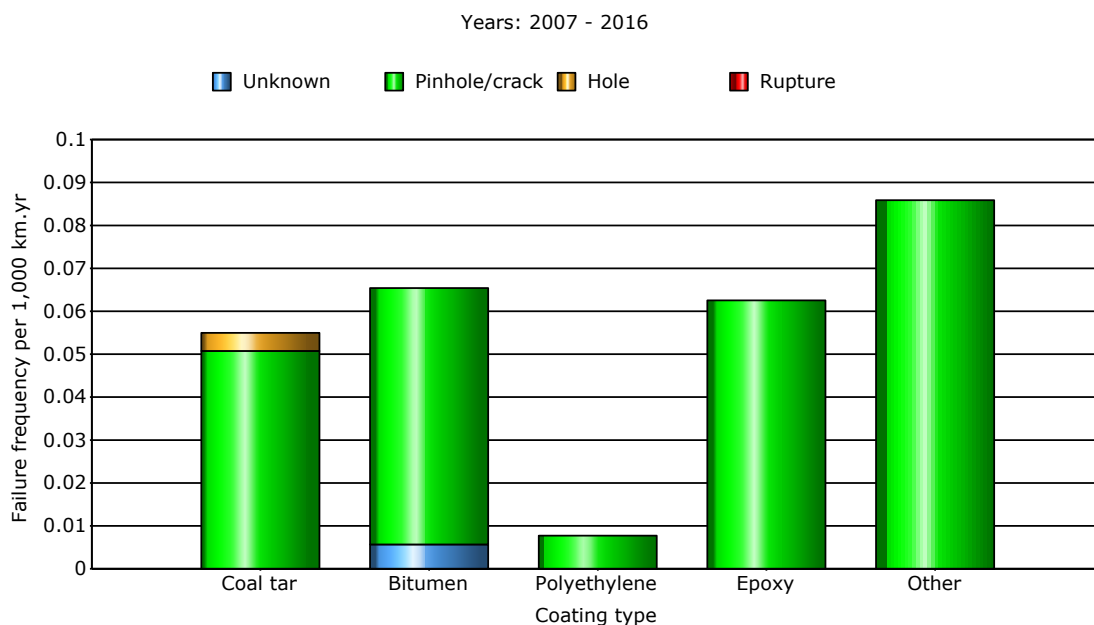
Years: 2007 - 2016

Figure 29: Relationship corrosion, size of leak and most common type of coating (2007-2016)

From these figures, it appears that older pipelines, with predominantly tar coatings, have higher failure frequencies. Nowadays, most transmission operators use modern coatings like polyethylene coatings.

Different protective measures are undertaken by pipeline owners to prevent leakage due to corrosion. These measures are for example cathodic protection and pipeline coating. In-line inspections and pipeline surveys also allow corrosion to be detected at an earlier stage.

Years: 1970 - 2016
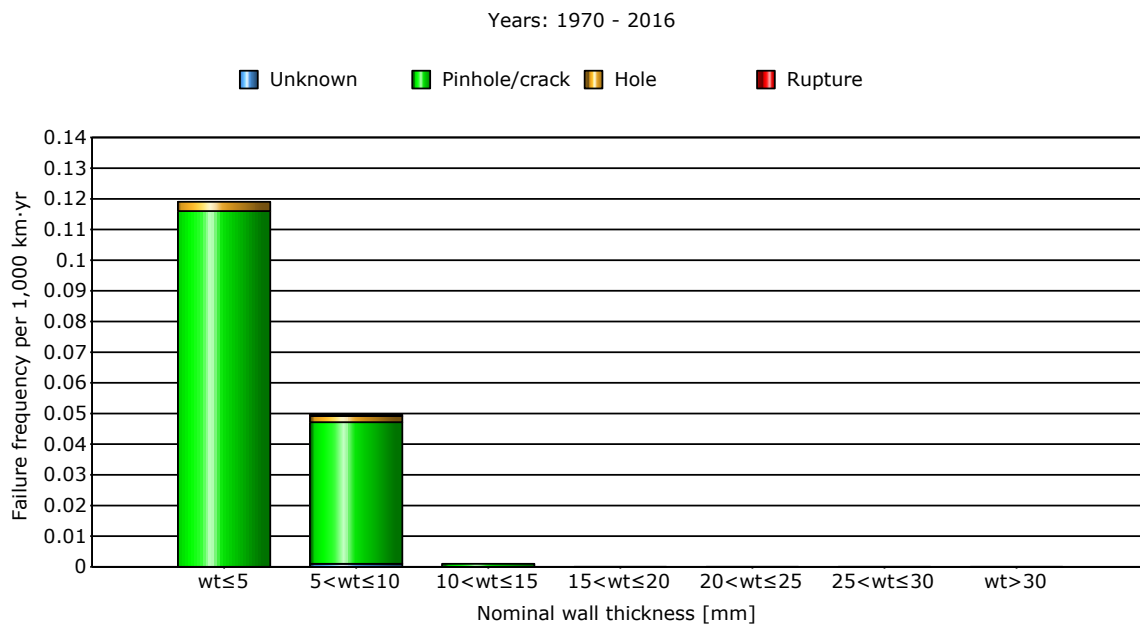
Figure 30: Relationship corrosion, size of leak and wall thickness (wt) (1970-2016)
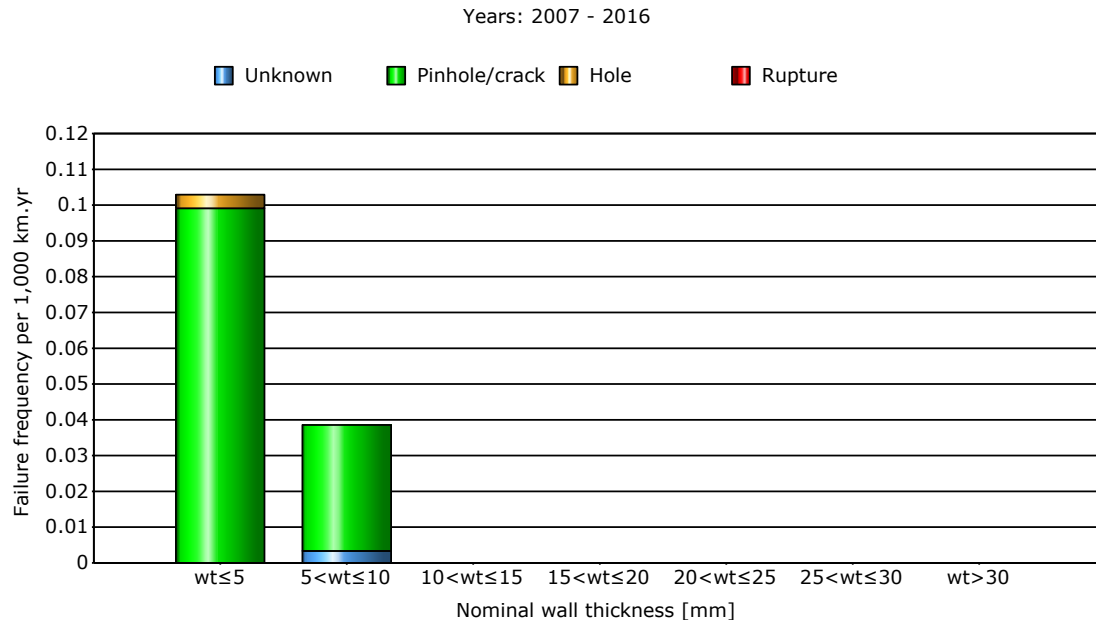
Years: 2007 - 2016

Figure 31: Relationship corrosion, size of leak and wall thickness (wt) (2007-2016)

From these figures some general conclusions can be drawn:

- The failure frequency decreases with increasing year of construction.

- The failure frequency decreases with increasing wall thickness. Corrosion is a time dependent phenomenon of deterioration of the pipelines. Corrosion takes place independently of the wall thickness, but the thinner the corroded pipeline wall, the sooner the pipeline fails. Corrosion on thicker pipelines takes longer before causing an incident and therefore has more chance to be detected by inspection programs.
- Pipelines coated with a polyethylene coating have a far lower failure frequency than pipelines with other types of coating.

For the corrosion incidents, two other types of data are registered:

- the location of corrosion (Internal, External, Unknown),
- the appearance of corrosion (General, Pitting, Cracking).
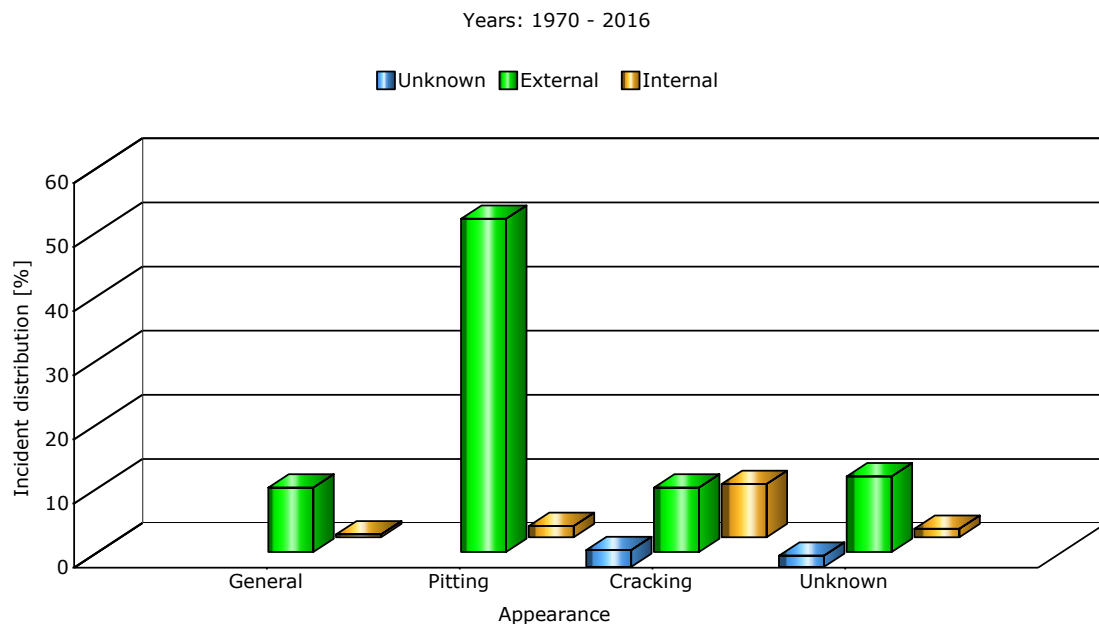
Figure 32: Breakdown of corrosion incidents on basis of location and appearance (1970-2016)

Years: 2007 - 2016

☐ Unknown ☐ External ☐ Internal
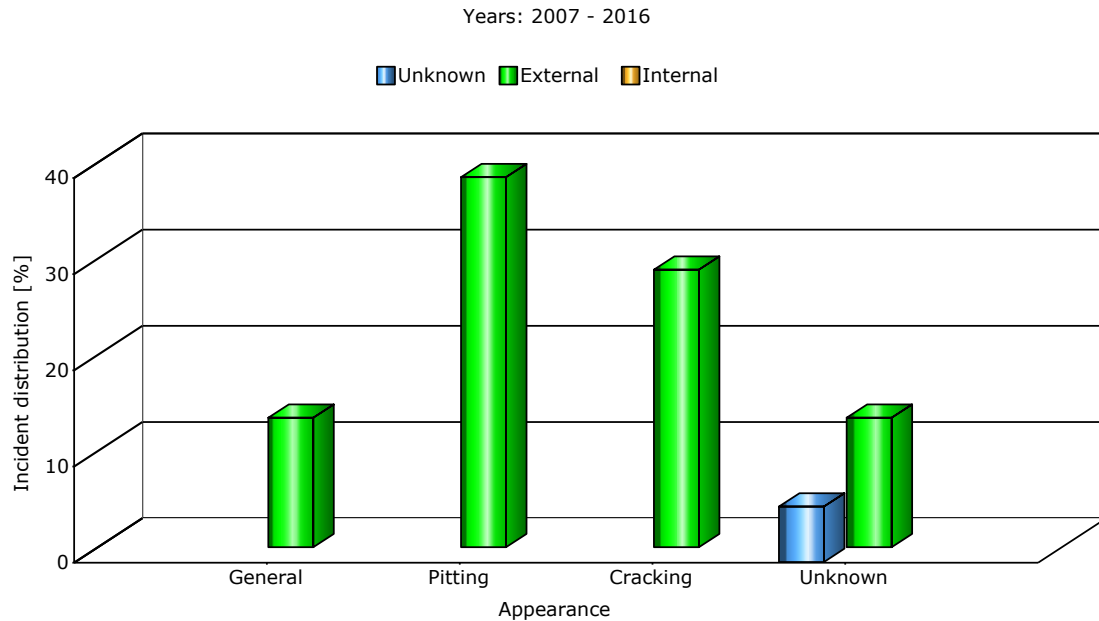
Figure 33: Breakdown of corrosion incidents on basis of location and appearance (2007-2016)

Figure 32 to Figure 33 demonstrate that pitting is the most common form of corrosion. Almost all corrosion incidents with pitting occur on the external surface of the pipelines.

Corrosion appearing as cracks is the second corrosion form to be found. These cracks are found on both the inner and the external surface of the pipelines. For the more recent period of 2007-2016 all cracks were found on the external surface.

General corrosion takes place evenly over the surface of the metal. This type of corrosion defects are almost always on the external surface of the pipeline.

3.3.2.4 Relationship between construction defect/material failures, leak size and design parameter

EGIG recognizes construction defects / material failures as one of the causes of pipeline incidents. During the last ten years, they represented about 17% of the pipeline incidents and are ranked third in the causes of incidents (Figure 15).

The EGIG database makes it possible to distinguish between construction defect and material failures.

Figure 34 to Figure 37 show the failure frequencies for the incident cause "construction defect" and "material failure" in relation to construction year and leak size for the periods 1970-2016 and 2007-2016.

From these figures, some general conclusions can be drawn: failure frequencies for "construction defects" and "material failure" generally decrease with increasing year of construction. New pipelines are less vulnerable to construction defects due to technical improvements.
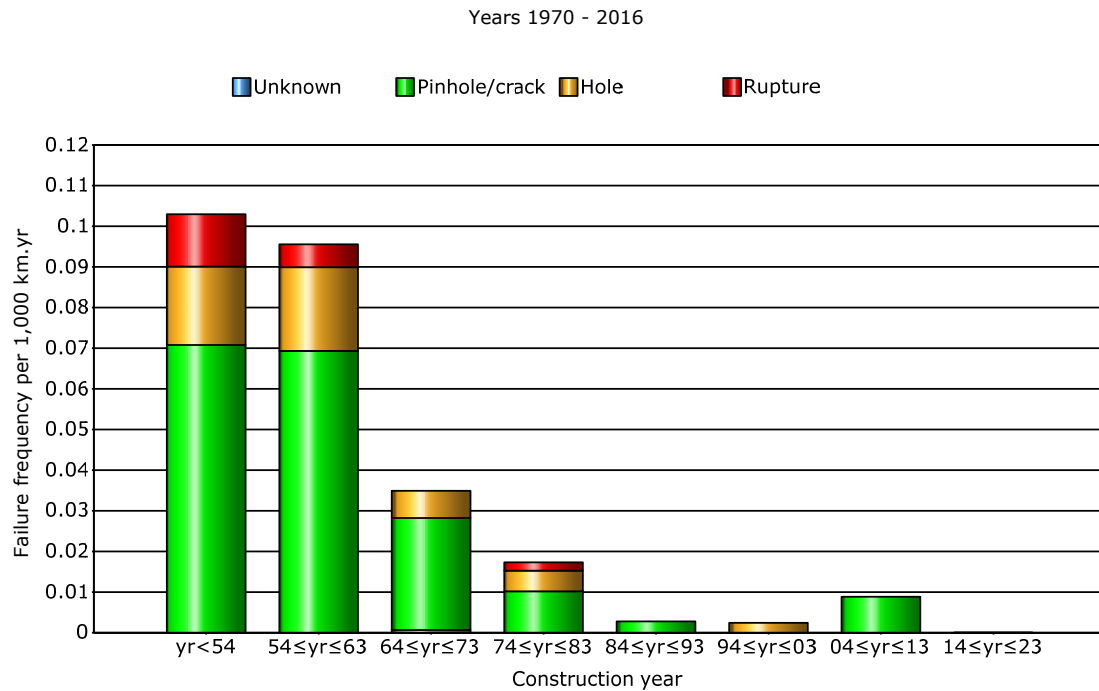
Years 1970 - 2016

Figure 34: Relationship construction defect, size of leak and year of construction (1970-2016)
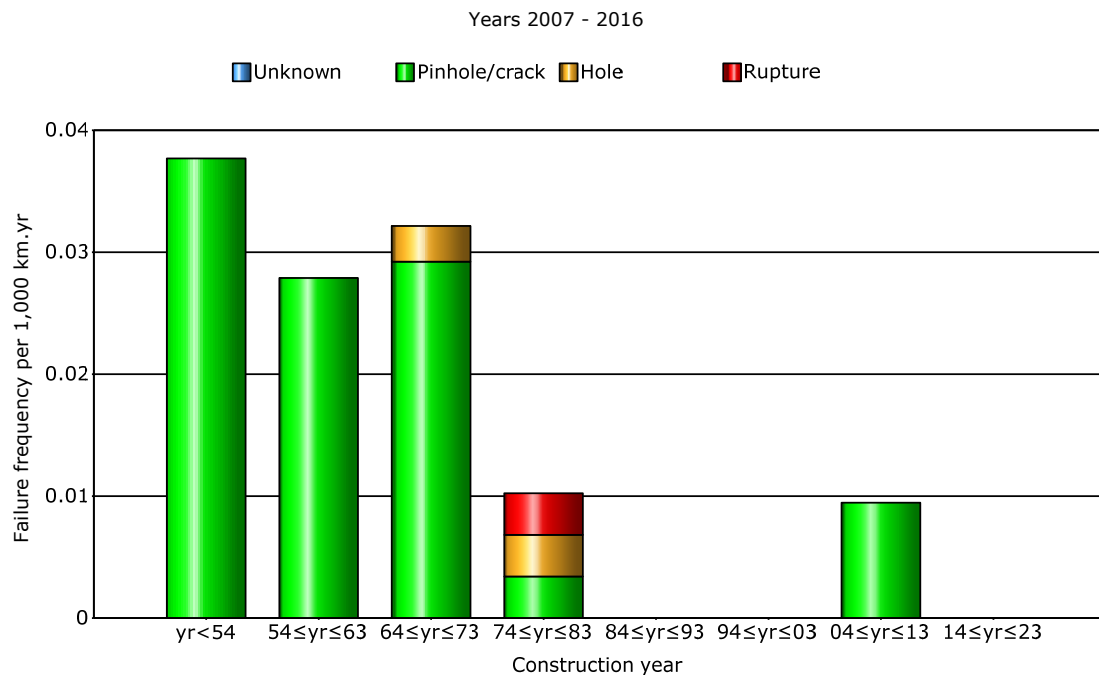
Years 2007 - 2016

Figure 35: Relationship construction defect, size of leak and year of construction (2007-2016)

Years 1970 - 2016

Unknown   Pinhole/crack   Hole   Rupture
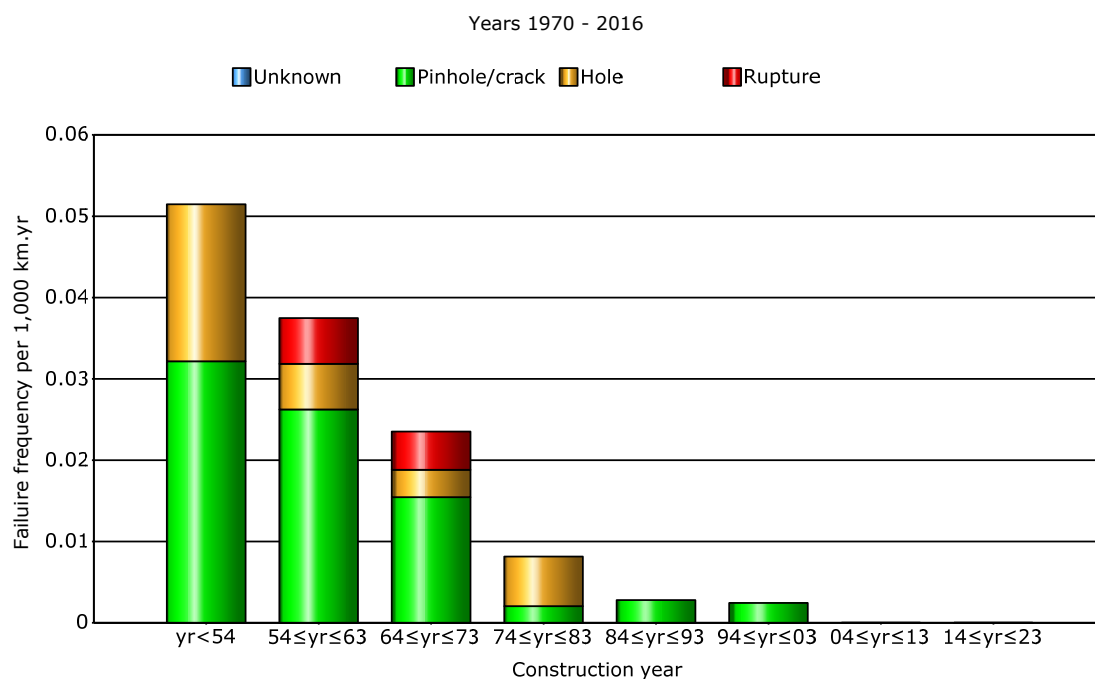
Figure 36: Relationship material failure, size of leak and year of construction (1970-2016)

Years 2007 -2016

Unknown   Pinhole/crack   Hole   Rupture
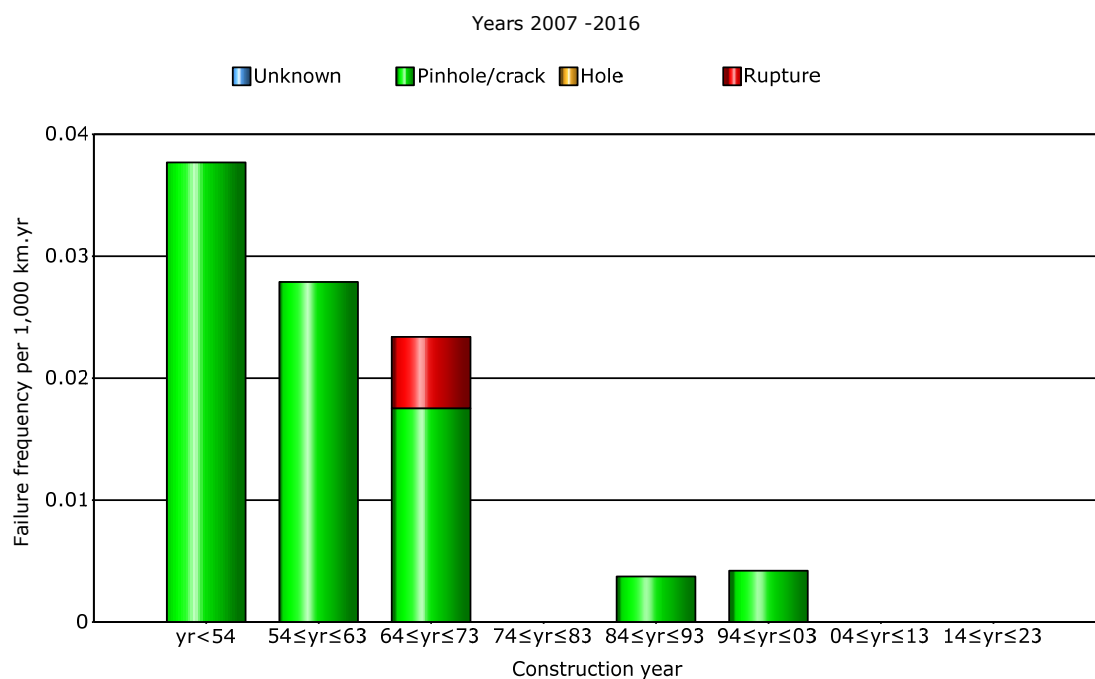
Figure 37: Relationship material failure, size of leak and year of construction (2007-2016)

Figure 38 and Figure 39 show the failure frequencies for the incident cause "material failure" for different classes of material grade and leak sizes for the periods: 1970-2016 and 2007-2016. Grade A material has the highest failure frequency for "material failure" in the period 1970-2016, but material failure was no cause of incidents on grade A pipelines in the period 2007-2016.
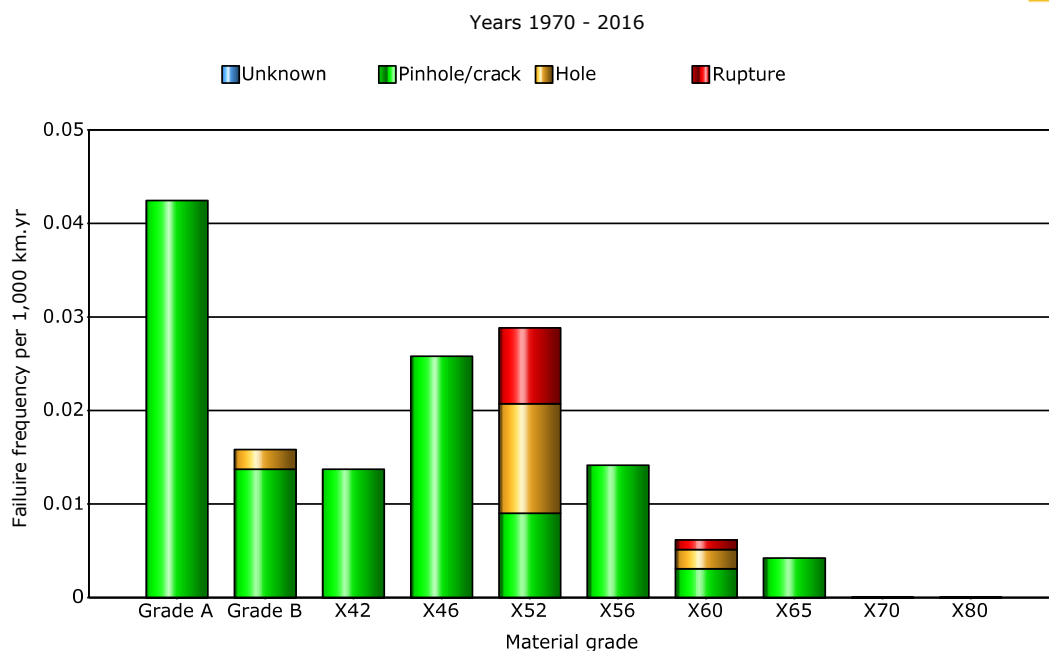
Figure 38: Relationship Material failure, size of leak and material grade (1970-2016)
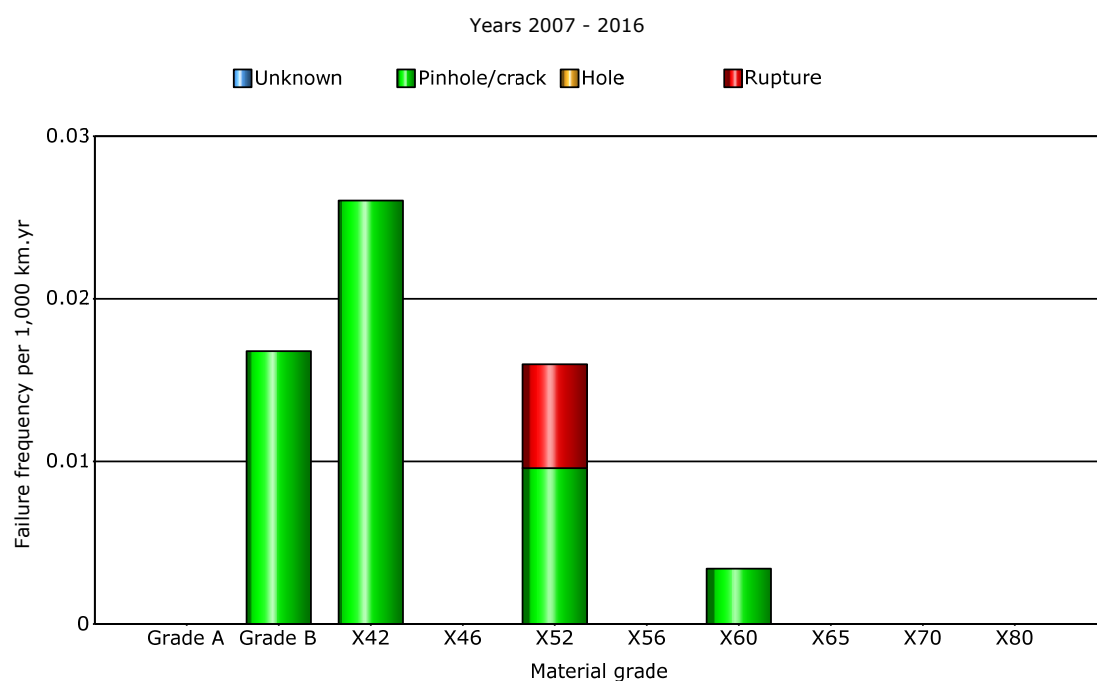
Figure 39: Relationship Material failure, size of leak and material grade (2007-2016)

3.3.2.5 Relationship between hot tap made by error, size of leak and design parameter

The term "hot tap made by error" means that a connection has been made by error to the gas transmission pipeline, assuming it was another pipeline.

Figure 40 and Figure 41 show the failure frequencies for the incident cause "hot tap made by error" for different pipeline diameter classes and leak sizes. The first graph present the failure frequency for the period 1970-2016 and the second graph for the period 2007-2016.

From these figures, some general conclusions can be drawn: the failure frequency for "hot tap made by error" decreases with increasing pipeline diameter. The same trend is true for every leak size.

Years: 1970 - 2016
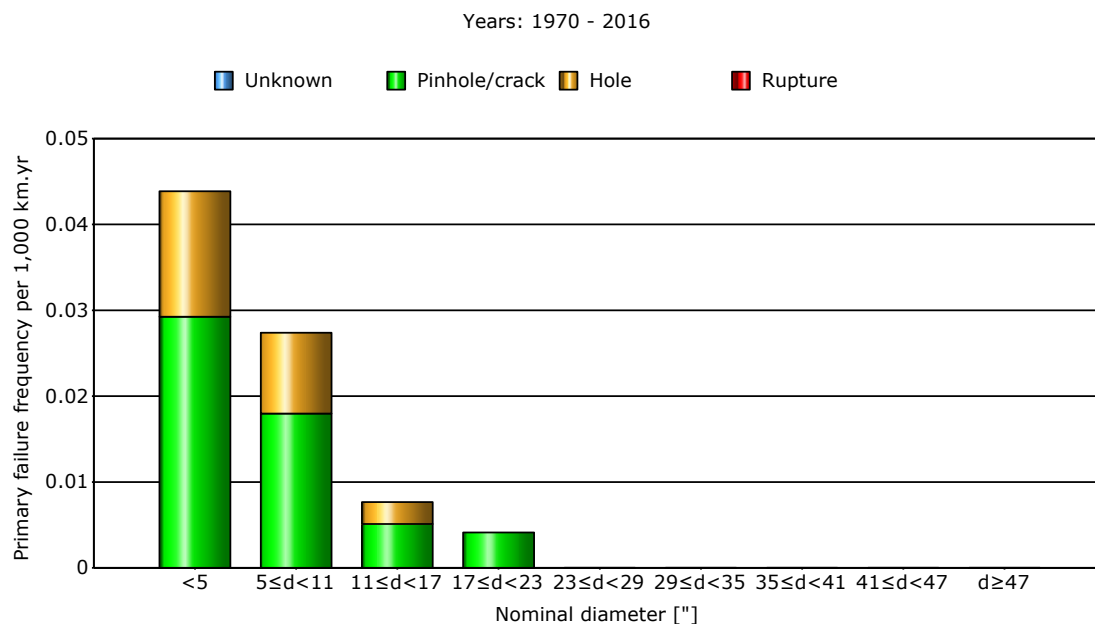
Figure 40: Relationship hot tap made by error, leak size and diameter (1970-2016)
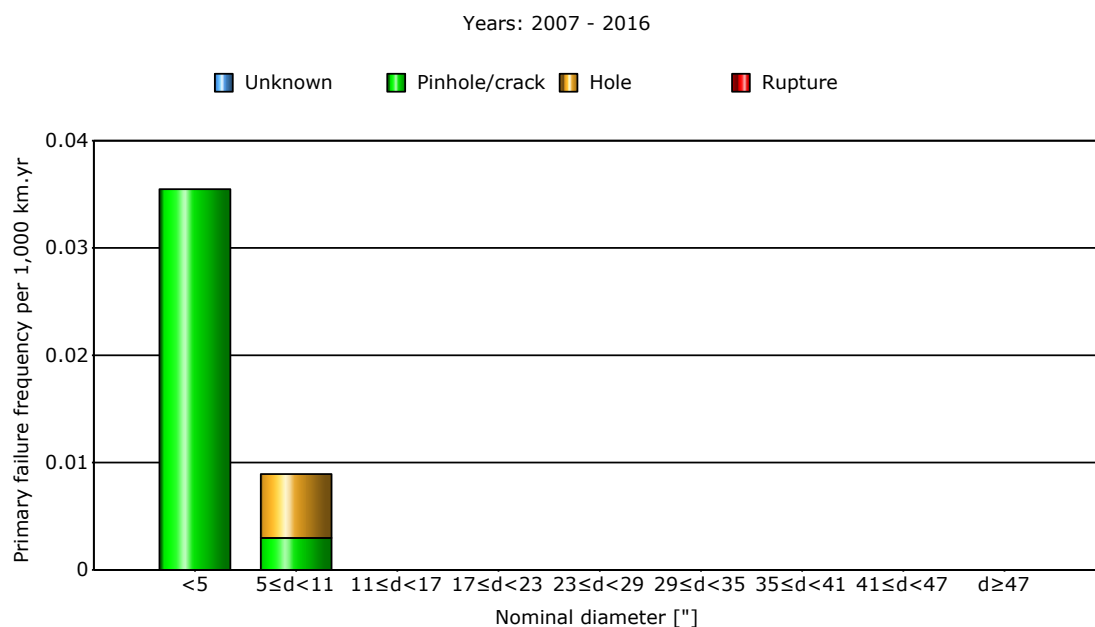
Years: 2007 - 2016

Figure 41: Relationship hot tap made by error, leak size and diameter (2007-2016)

3.3.2.6 Ground movement

Ground movement is responsible for 15% of the incidents over the last ten years (see Figure 15). Figure 42 and Figure 43 show the failure frequencies for the incident cause "ground movement" for different pipeline diameter classes and leak sizes.

Both graphs present the failure frequency per pipeline diameter class, one for the period 1970-2016, the second for the period 2007-2016.

From these figures some conclusions can be drawn:
For the period 1970-2016 failure frequencies for "ground movement" generally decrease with increasing pipeline diameter. The failure frequency for the diameter $\geq$ 47'' is caused by one ground movement incident.
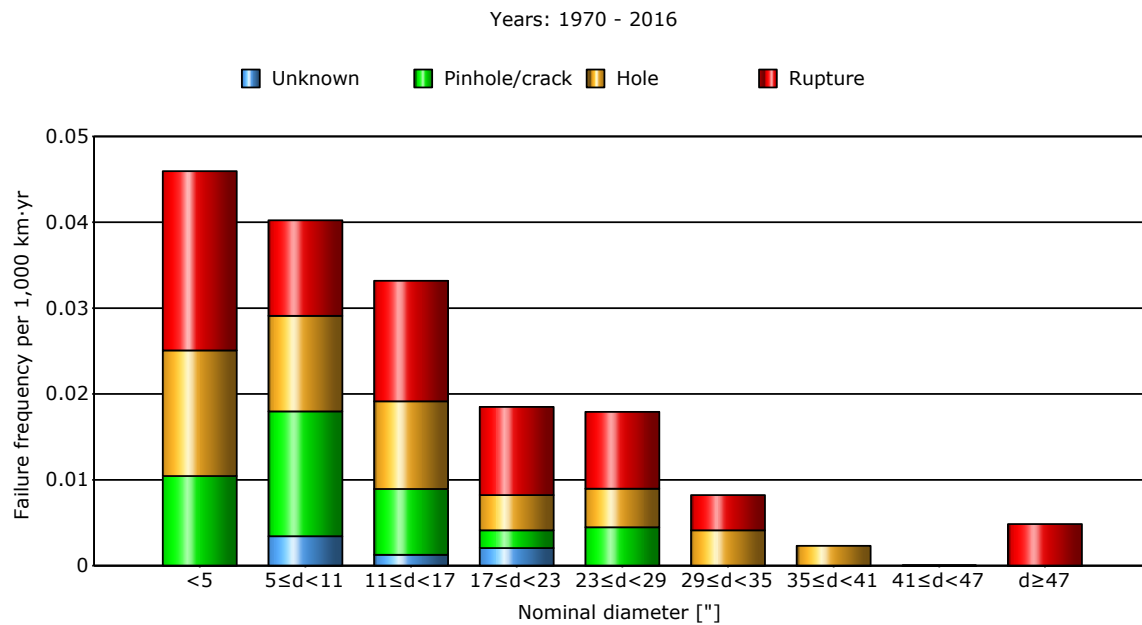
Figure 42: Relationship ground movement, size of leak and diameter (1970-2016)

Years: 2007 - 2016
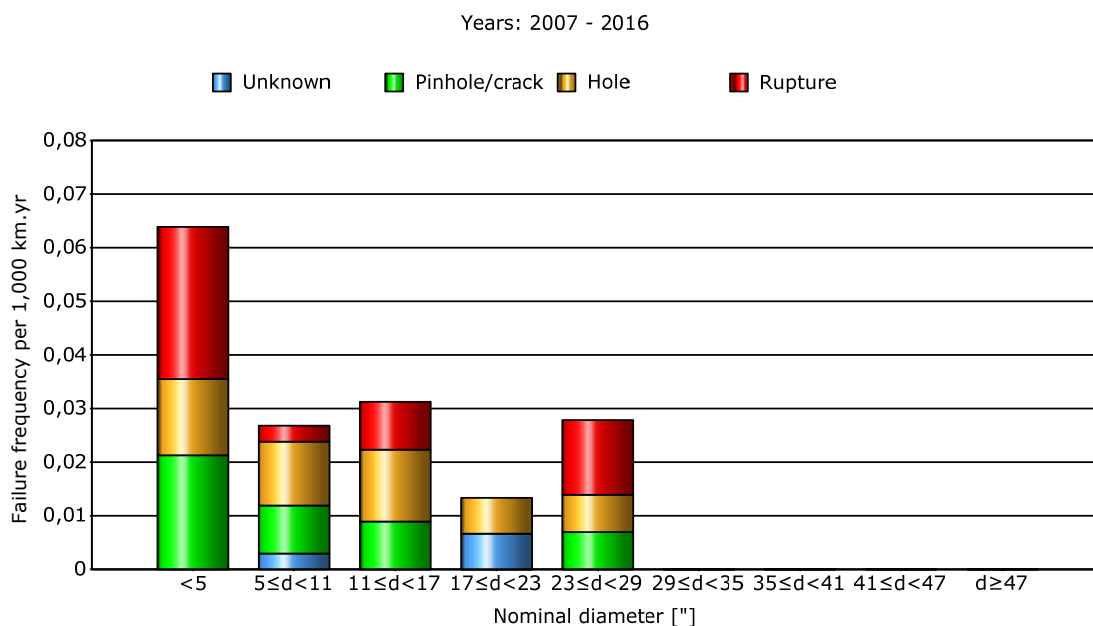
Figure 43: Relationship ground movement, size of leak and diameter (2007-2016)

There are many types of "Ground movement" incidents. Figure 44 and Figure 45 give more details on the different types of ground movements that caused a pipeline incident. Landslides are by far the most common type causing a ground movement incident.
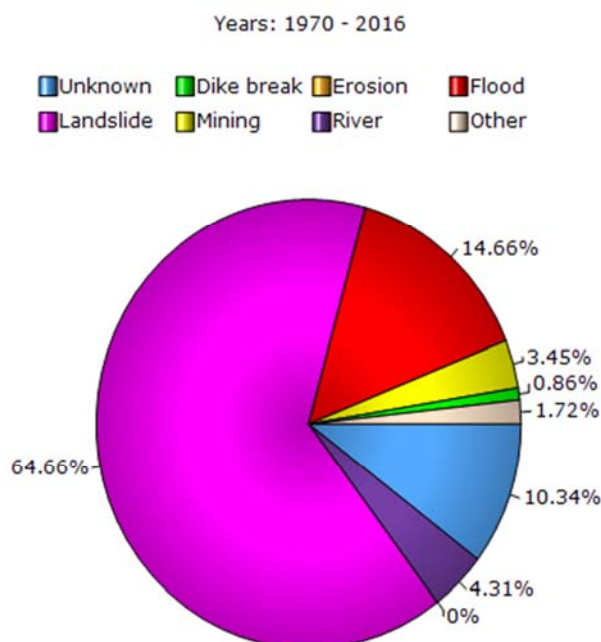
Figure 44: Distribution of the sub-causes of ground movement (1970-2016)
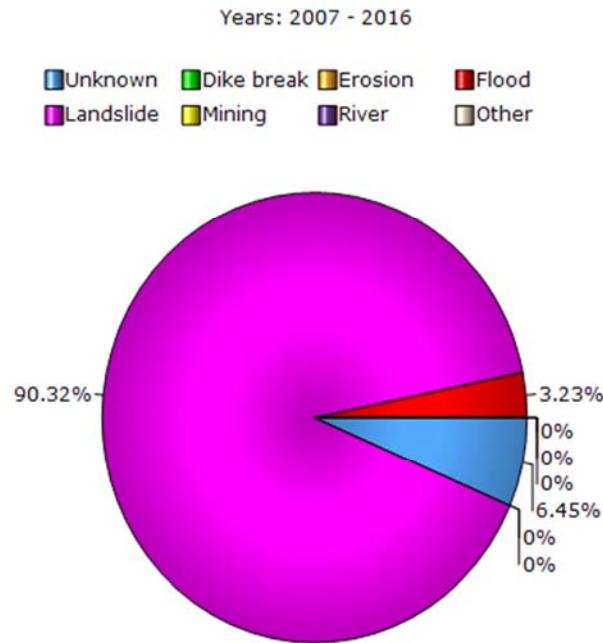
Figure 45: Distribution of the sub-causes of ground movement (2007-2016)

3.3.2.7 Other and unknown

29.3% of the incidents in the category "other and unknown" are caused by "lightning". Within the period 1970-2016, 29 incidents due to lightning have been recorded in the EGIG database, which represents a failure frequency due to lightning equal to 0.0066 per 1,000 km·yr. EGIG examined the distribution of the consequences of lightning in terms of leak sizes. Out of 29 incidents, 27 were pinholes/cracks and 2 resulted in a hole.

No incidents were recorded that were caused by earthquakes.

3.4 Other analyses

3.4.1 Relationship between corrosion and age

In this analysis, the failure frequency of corrosion incidents has been studied as a function of construction year and the age of the pipeline at the moment of the incident.
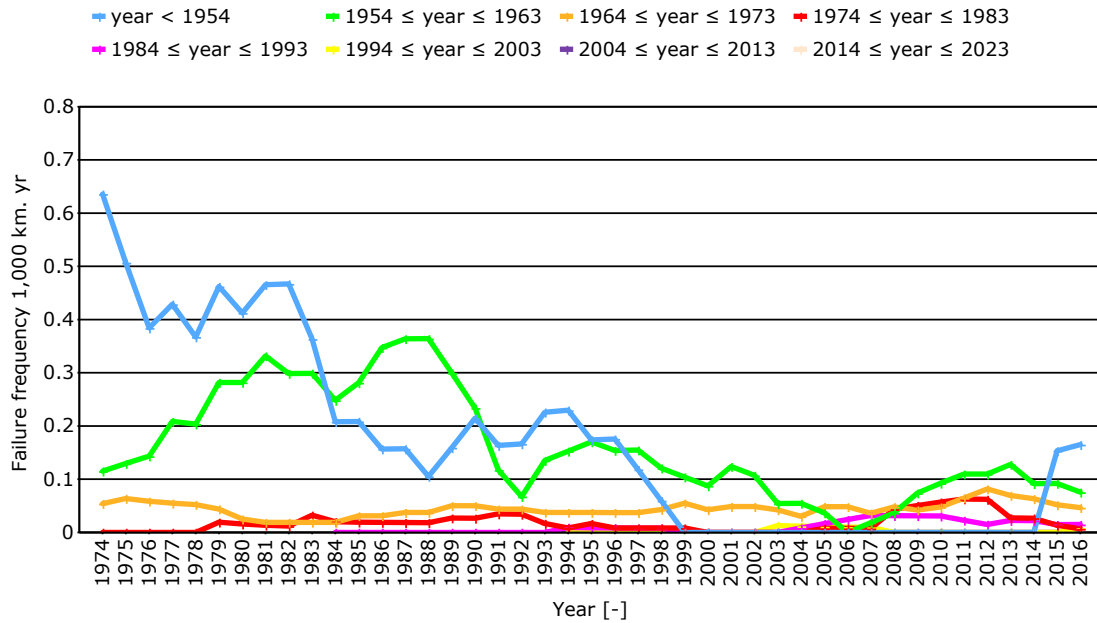
Figure 46: Relationship 5 year moving average failure frequency of corrosion incidents and year of construction
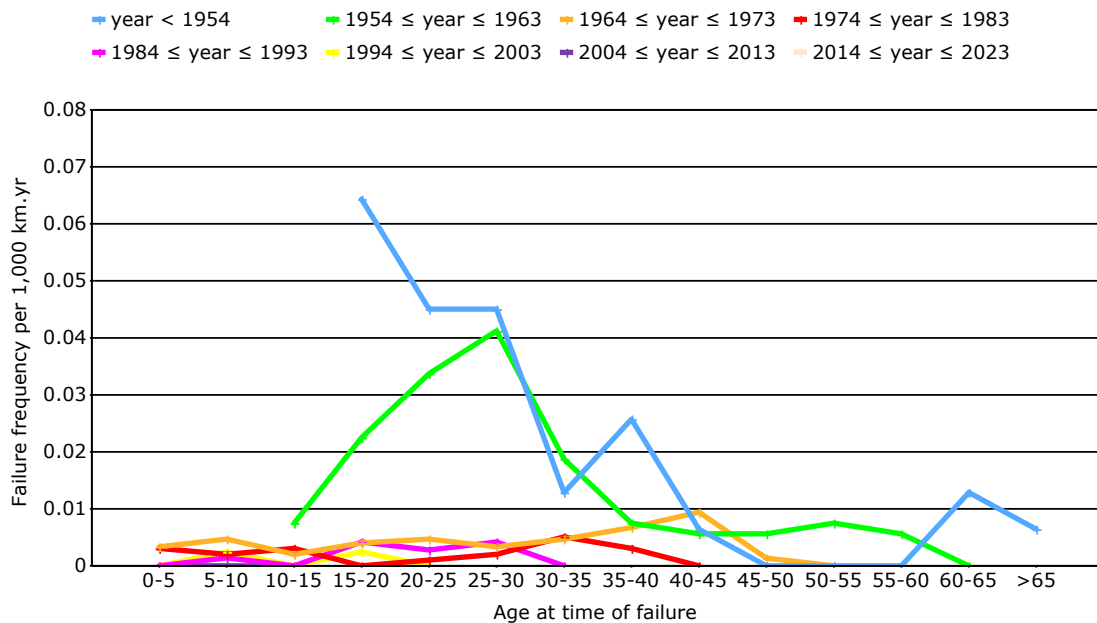
Figure 47: Relationship failure frequency of corrosion incidents and the age at the time of failure.

Explanation Figure 47.

Taking for instance a pipeline constructed before 1954: the failure frequency 15 to 20 years after construction is 0.064 per 1,000 km·yr, whereas it is 0.013 per 1,000 km·yr after 30-35 years. EGIG started data collection from 1970 on, therefore no data is available for failure frequencies at the early life stage of pipelines constructed before 1954 or pipelines constructed between 1954 and 1964.

The first conclusion of Figure 47 is that early constructed pipelines (before 1964) had higher failure frequencies than recently constructed pipelines at the same age. A second conclusion is that the corrosion failure frequencies of pipelines constructed in the last decades are independent of their age and their construction year class.

3.4.2   Ignition of releases

Fortunately, not every gas release ignites, which limits the consequences of the incidents. In the period 1970-2016, only 5 % of the gas releases recorded in the EGIG database ignited. Pipeline ruptures with ignition can cause severe societal consequences. This is especially the case for pipelines with larger diameters. Figure 48 shows that gas releases from large diameter pipeline ruptures at high pressure have ignited more frequently than smaller diameter pipeline ruptures at lower pressure. This data is based on only a few ruptures. Care should be taken when using it as an ignition probability, as the uncertainty is high. In the paper (Michael R. Acton, 2008) ''Ignition Probability for High Pressure Gas update to 2016'' an analysis is made of ignition probabilities. This paper shows that even ruptures of large diameter pipelines and high pressure not always ignite.

Information on ignited releases is presented in Table 7 as a function of size of leak and pipeline diameter.

Size of leak	% of releases with ignition
Pinhole-crack	4.5
Hole	2.2
Rupture (all diameters)	14.4
Rupture ≤ 16 inches	10.0
Rupture > 16 inches	42.3

Table 7: Ignition of releases per leak type
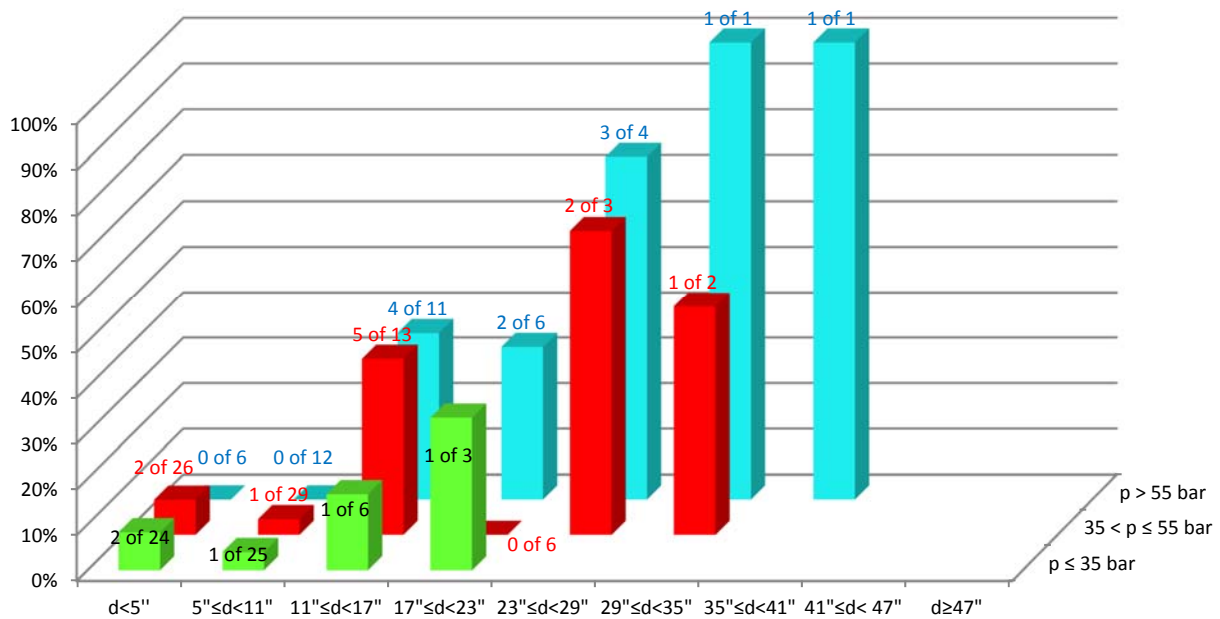
Figure 48: Percentages of ruptures that ignited subdivided in diameter and pressure (1970-2016)

3.4.3   *Injuries and fatalities*

EGIG database also registers qualitative information about the consequences of incidents, amongst other injuries and fatalities that, unfortunately, occurred in some of them.

EGIG studied the injuries and fatalities among different groups involved in pipeline incidents. These groups are:

- employees or contractors of the transmission system operator;
- third party directly involved in causing the incidents (for example digger drivers in the case of external interference incidents);
- emergency services (firefighters, medical assistance);
- the general public.

The EGIG database contains a total of 1,366 incidents, but as is shown in Figure 49 only a small percentage leads to injuries and fatalities. The highest fatality and injury rate can be found among the people who are directly involved in causing the incident. In 6 cases (0.44%) these incidents caused fatalities among the people causing the incident. Two incidents involved fatalities among the public. In Figure 50 it can be seen that the fatalities mainly occurred when the incident was a pipeline rupture.
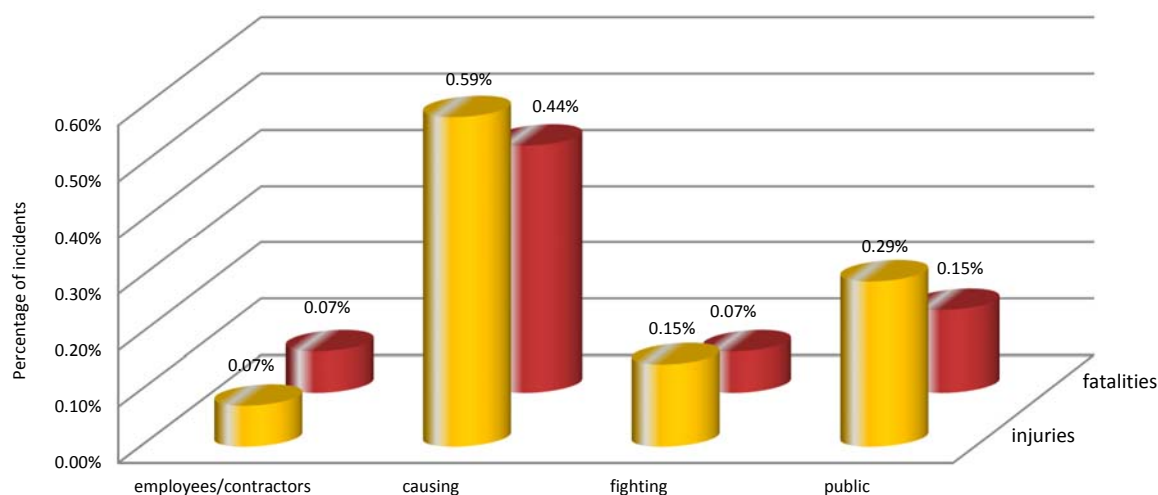
Figure 49: Percentage of accidents of groups involved in pipeline incidents (1970-2016)
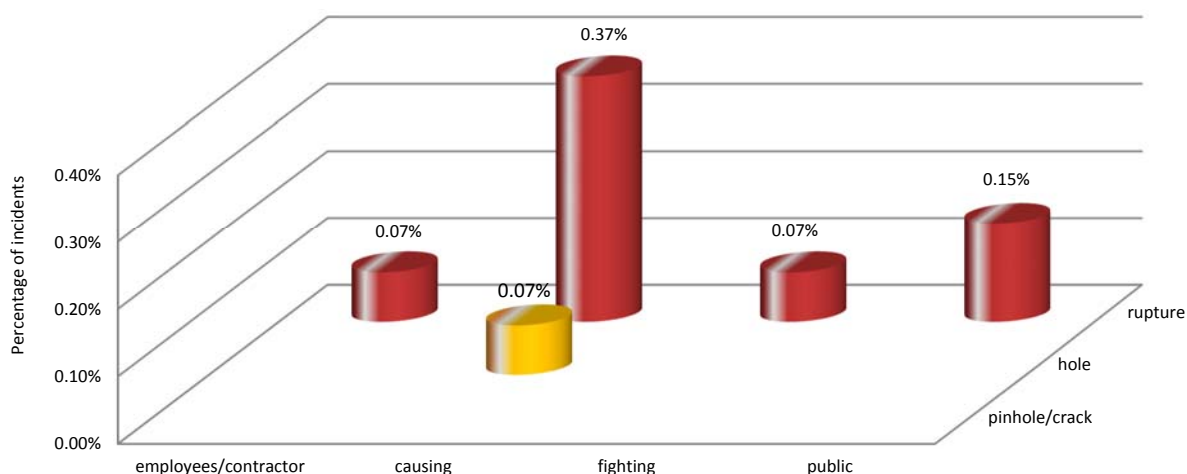
Figure 50: Percentage fatalities of accidents of groups as a function of leak size (1970-2016)

Although the occurrence of injuries and fatalities is low, safety remains the highest priority for the gas transmission companies.

3.4.4   Detection of incidents

Incidents are detected in different ways. Table 8 shows the distribution per detection type. People directly involved to the transmission networks, like patrol, contractors and staff, are the most common detector (approximately 40% of the incidents). In the period 1970-2016, 16% of the incidents were detected by the patrols, 15% by contractors and 9% by staff.

Public also detect a significant part of the incidents. In the period between 1970-2016 public detected 35% of the incidents. In the last 10 years (2007-2016) this number decreased to approximately

20%. The number of incidents detected by landowners has significantly increased in the last ten years.

Detection	Incident distribution 1970 – 2016 [%]	Incident distribution 2007–2016 [%]
Public	35.1	20.2
Patrol + Contractors + Staff	39.9	42.3
Unknown	7.0	1.4
Landowner	5.4	14.9
Distribution company	4.8	3.4
Other	5.7	10.6
In-line inspection	2.1	7.2

Table 8: Detection of incidents
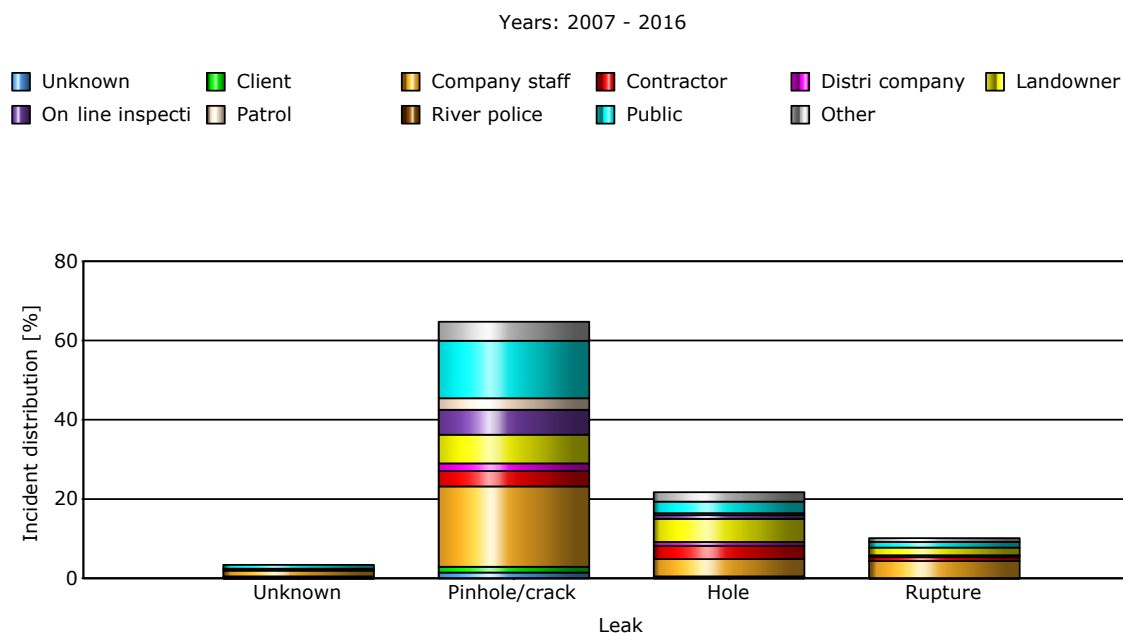
Figure 51: Detection of incidents per leak size (2007-2016)

Figure 51 shows that most pinhole/cracks are detected by company staff and public. Holes and ruptures are mainly detected by company staff, landowners, contractors and public.

4 CONCLUSIONS

- The EGIG database is a valuable source of information on European gas pipelines and incidents.

- EGIG has maintained and expanded the European Gas pipeline incident database. Seventeen gas transmission system operators in Europe now collect incident data on more than 142,794 km of pipelines every year. The total exposure, which expresses the length of a pipeline and its period of operation, is 4.41 million km·yr.

- In the EGIG database 1,366 pipeline incidents are recorded in the period from 1970-2016.

- The history of incidents collected in the database gives reliable failure frequencies. The overall failure frequency over the period 1970-2016 is equal to 0.31 incidents per year per 1,000 km.

- The five year moving average failure frequency in 2016, which represents the average failure frequency over the past 5 years, equals 0.134 per year per 1,000 km.

- The five year moving average and overall failure frequency have reduced consistently over the years, although it has tended to stabilise over recent years.

- Incidents caused by external interference and ground movement are characterised by potentially severe consequences. This emphasises their importance to pipeline operators and authorities.

- Corrosion as a primary cause has now the same frequency rate as external interference, although consequences are much less severe.

- Over the last ten years, external interference, corrosion, construction defects and ground movement, represent 28%, 25%, 18% and 15% respectively of the pipeline incidents reported.

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APPENDIX 1: Statistics

Primary failure frequencies over different time intervals

Period	Interval [years]	Number of incidents	Total system exposure ·10^6 km·yr	Primary failure frequency per 1,000 km·yr	95% LL Primary failure frequency per 1,000 km·yr	95% UL Primary failure frequency per 1,000 km·yr
1970 – 2007	7th report, 38 years	1,173	3.15	0.372	0.351	0.394
1970 – 2010	8th report, 41 years	1,249	3.55	0.352	0.333	0.372
1970 – 2013	9th report, 44 years	1,309	3.98	0.329	0.311	0.347
1970 – 2016	10th report, 47 years	1,366	4.41	0.310	0.294	0.327
1977 - 2016	40 years	1,143	4.12	0.278	0.262	0.294
1987 - 2016	30 years	723	3.44	0.210	0.195	0.226
1997 - 2016	20 years	418	2.53	0.165	0.150	0.182
2007 - 2016	10 years	208	1.39	0.150	0.130	0.172
2012 - 2016	5 years	97	0.716	0.136	0.110	0.165

Table 9: Primary failure frequencies and confidence intervals over different time intervals

Leak size	Primary failure frequency per 1,000 km·yr	95% LL Primary failure frequency per 1,000 km·yr	95% UL Primary failure frequency per 1,000 km·yr
Unknown	0.001	0.000	0.008
Pinhole/crack	0.087	0.066	0.111
Hole	0.028	0.017	0.043
Rupture	0.020	0.011	0.033

Table 10: Primary failure frequencies and confidence intervals per leak size (period 2012–2016)

Cause	Primary failure frequency per 1,000 km·yr	95% LL Primary failure frequency per 1,000 km·yr	95% UL Primary failure frequency per 1,000 km·yr
External interference	0.144	0.133	0.156
Corrosion	0.052	0.045	0.059
Construction defect / Material failure	0.051	0.045	0.058
Hot tap made by error	0.014	0.011	0.018
Ground movement	0.026	0.022	0.032

Table 11: Primary failure frequencies and confidence intervals per cause (1970-2016)

Cause	Primary failure frequency per 1,000 km·yr	95% LL Primary failure frequency per 1,000 km·yr	95% UL Primary failure frequency per 1,000 km·yr
External interference	0.064	0.055	0.075
Corrosion	0.034	0.027	0.042
Construction defect / Material failure	0.022	0.017	0.029
Hot tap made by error	0.006	0.003	0.009
Ground movement	0.023	0.017	0.029

Table 12: Primary failure frequencies and confidence intervals per cause (1997-2016)

Cause	Primary failure frequency per 1,000 km·yr	95% LL Primary failure frequency per 1,000 km·yr	95% UL Primary failure frequency per 1,000 km·yr
External interference	0.043	0.032	0.055
Corrosion	0.037	0.028	0.049
Construction defect / Material failure	0.027	0.019	0.037
Hot tap made by error	0.006	0.002	0.011
Ground movement	0.022	0.015	0.032

Table 13: Primary failure frequencies and confidence intervals per cause (2007-2016)

Cause	Primary failure frequency per 1,000 km·yr	95% LL Primary failure frequency per 1,000 km·yr	95% UL Primary failure frequency per 1,000 km·yr
External interference	0.032	0.020	0.048
Corrosion	0.027	0.016	0.041
Construction defect / Material failure	0.021	0.012	0.035
Hot tap made by error	0.003	0.000	0.010
Ground movement	0.031	0.019	0.047

Table 14: Primary failure frequencies and confidence intervals per cause (2012-2016)

APPENDIX 2: Poisson law

A confidence interval is made to take uncertainty into account. To calculate a confidence interval the population is assumed to have a known distribution. The assumption is made that the number of incidents follows Poisson's law, also called law of rare events.

Exact Poisson confidence limits for the estimated rate are found as the Poisson means, for distributions with the observed number of events and probabilities relevant to the chosen confidence level, divided by time at risk. The relationship between the Poisson and chi-square distributions is employed here

$$Y_i = \frac{\left(\chi^2_{2Y,\frac{\alpha}{2}} \right)}{2}$$

$$Y_u = \frac{\left(\chi^2_{2(Y+1),1-\frac{\alpha}{2}} \right)}{2}$$

where Y is the observed number of events, Y_l and Y_u are lower and upper confidence limits for Y respectively, $\chi^2_{v,\alpha}$ is the chi-square quantile for upper tail probability on v degrees of freedom.

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Ulm K. A simple method to calculate the confidence interval of a standardized mortality ratio. American Journal of Epidemiology 1990;131(2):373-375.