



GAS PIPELINE INCIDENTS

**9th Report of the European Gas Pipeline Incident Data Group
(period 1970 – 2013)**

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)
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European Gas Pipeline Incident Data Group (EGIG):**

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

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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 (European Gas pipeline Incident data Group). Presently, EGIG is a cooperation of seventeen major 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 help pipeline operators to establish failure frequencies and causes of failures in the gas transmission pipeline systems.

CONCLUSIONS

- 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 143,000 km of pipelines every year. The total exposure, which expresses the length of a pipeline and its period of operation, is 3.98 million km·yr.
- In the EGIG database 1309 pipeline incidents are recorded in the period from 1970-2013.
- The history of incidents collected in the database gives reliable failure frequencies. The overall incident frequency is equal to 0.33 incidents per year per 1,000 km over the period 1970-2013.
- The 5-year moving average failure frequency in 2013, which represents the average incident frequency over the past 5 years, equals 0.16 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.
- Incidents caused by external interference and ground movement are characterised by potentially severe consequences which emphasises their importance to pipeline operators and authorities.
- Corrosion as a primary cause has increased over the last five years and is now of the same magnitude as external interference, although consequences are much less severe.
- Over the last ten years, external interference, corrosion, construction defects and ground movement, represent 35%, 24%, 16% and 13% 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 frequencies and probabilities 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 (from 1970 onwards for most of the companies), the EGIG database is a valuable and reliable source of information. The results of the database present an average of all participating companies and do not highlight the geographical differences.

Uniform 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, for example, the incident frequency per design parameter (diameter, pressure, wall thickness) but not per combination of design parameters.

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.

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

2 EGIG DATABASE

2.1 Definition

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

2.2 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.

2.3 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 bar
 - 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.

2.4 Contents

The EGIG database contains general information about the major 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
- 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 the individual 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.

2.5 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 of pipeline data over different time intervals. In this report, the statistics of the whole database (covering the period 1970-2013), but also the most important statistics over the last 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 (1970-2013). To show the information of a more recent period, EGIG also uses a period of the last ten years (2004-2013) and 5 year moving average graphs to demonstrate developments and trends of several statistics.

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 which 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. In other words, with the EGIG database it is possible to establish the incident frequency of 42-inch pipelines or to establish the incident frequency of pipelines with a wall thickness of 15 mm, but it is not possible to calculate the incident frequency of the 42-inch pipelines with a wall thickness of 15 mm.

3 ANALYSES AND RESULTS

3.1 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: company A 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 design parameter, e.g. per diameter or per depth of cover.

The failure frequencies are calculated by dividing the number of incidents by a system exposure.

5-year moving average: In order to illustrate trends, a 5-year moving average has been introduced. The 5-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.

Ageing: Ageing is the process of growing old and showing the effects of increasing age. For EGIG purposes an ageing analysis has been carried out in order to study the impact of the age of the pipelines on their failure frequencies. This analysis was made by comparing the failure frequencies of different pipeline age categories. Particularly the effect of age on corrosion is discussed more intensively in this report.

3.2 Trends of the European 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 parameters 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.

3.2.1 Total length

The total length of the European gas transmission pipelines system in EGIG is constantly increasing. In 2010 the annual length was equal to 135,211 km against 143,727 km in 2013. There is a steady growth of the system length that includes two new members that were introduced in the last 3 years and the construction and acquisition of pipelines by existing members. The evolution of the total length of the system is shown in Figure 1 and is also given per category (diameter, pressure, etc.) in Figure 2 to Figure 8.

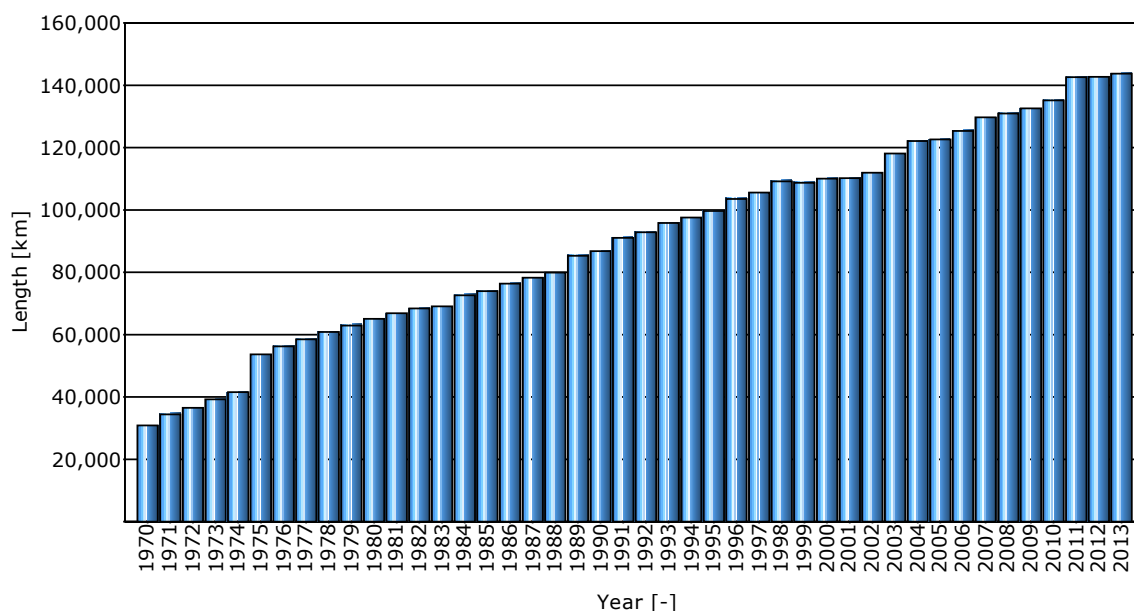


Figure 1: Total length of the European gas transmission system in EGIG

Figure 1 shows a steady 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 new members joining EGIG.

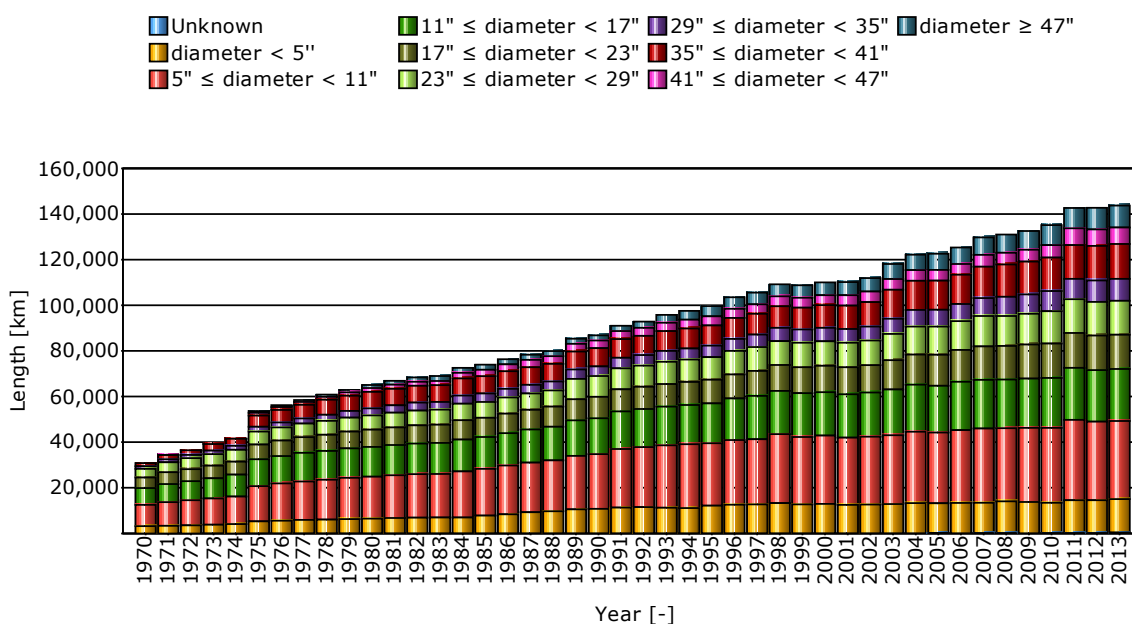


Figure 2: Total length per diameter

Figure 2 demonstrates that the 5"≤diameter<11" and the 11"≤diameter<17" classes are still the most commonly used.

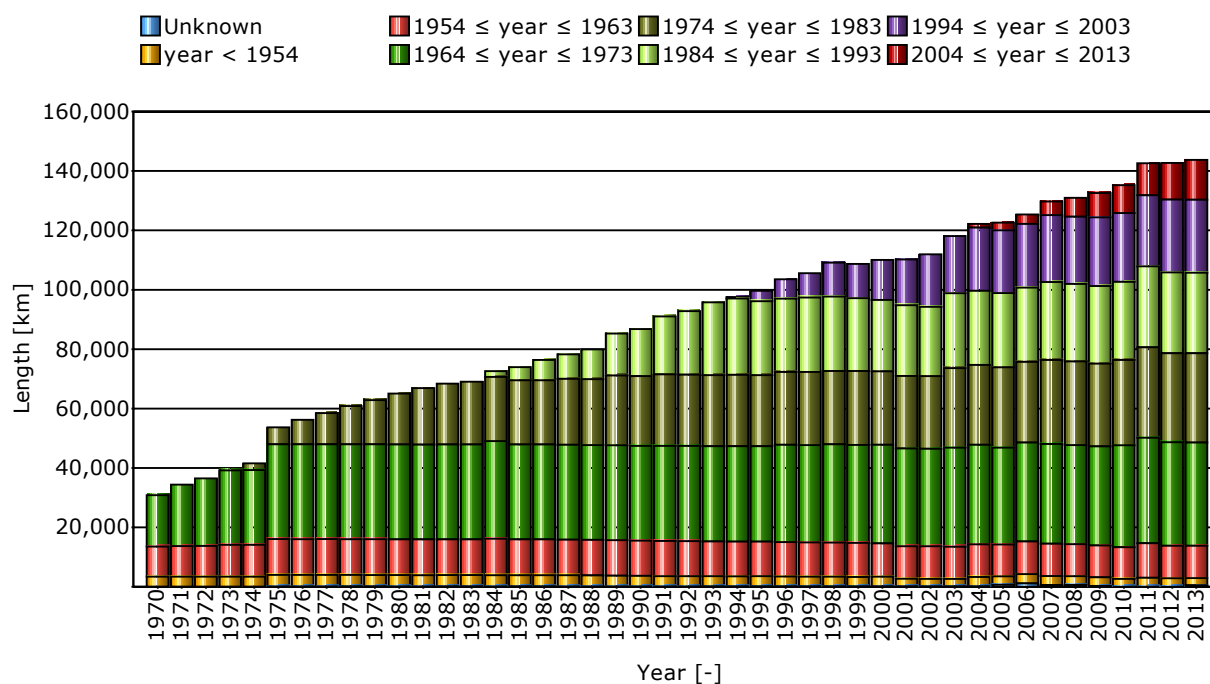


Figure 3: Total length per year of construction

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.

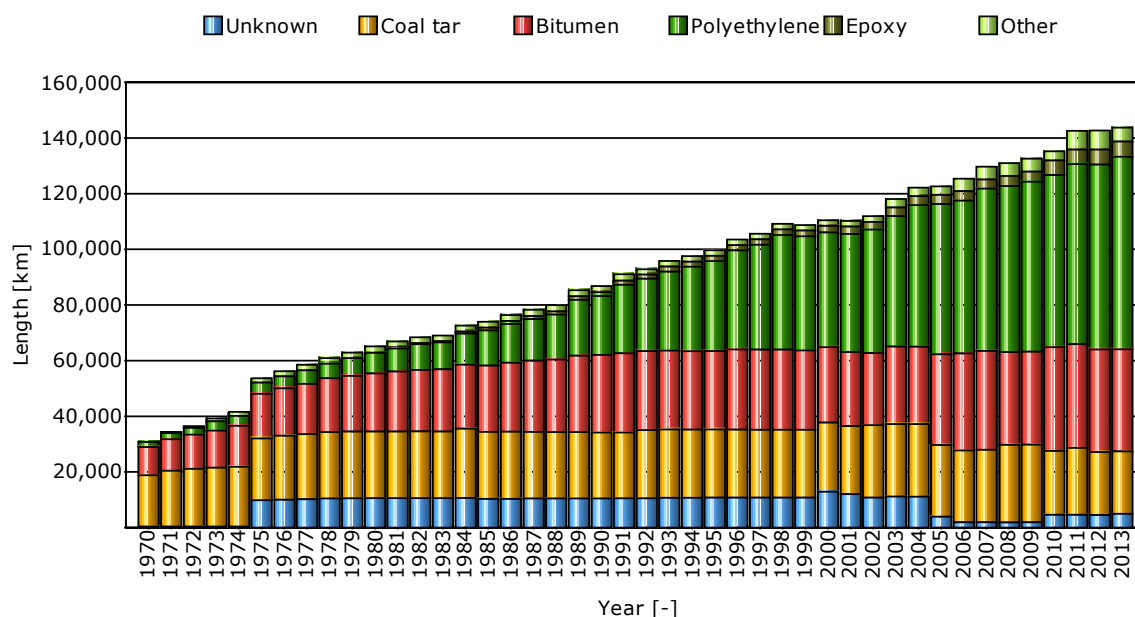


Figure 4: Total length per type of coating

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.

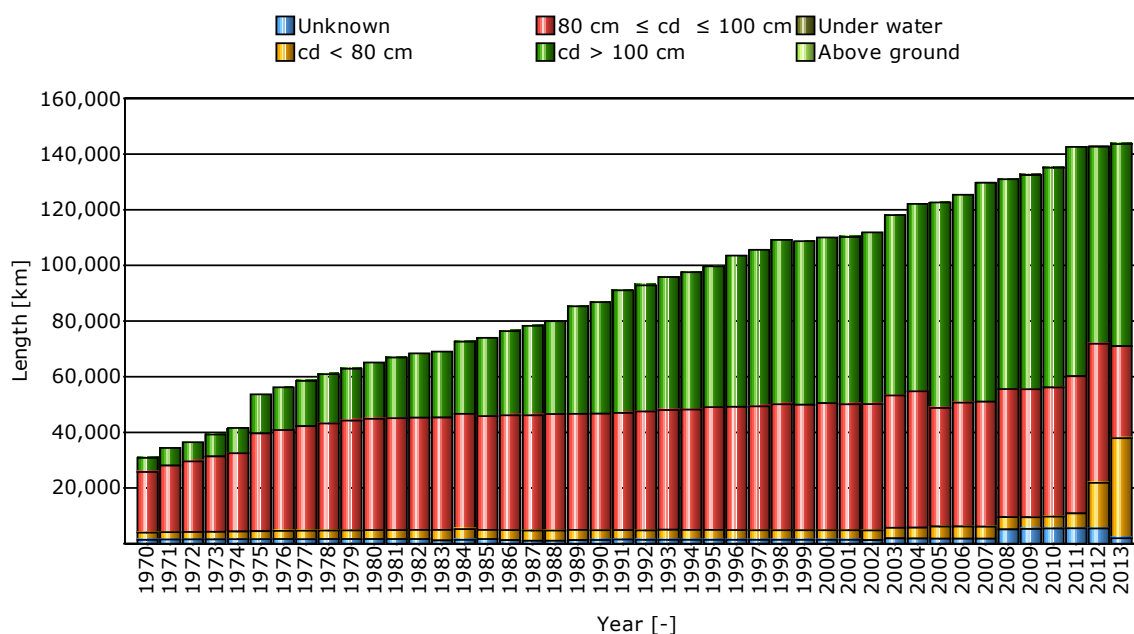


Figure 5: Total length per depth of cover (cd)

Figure 5 shows that most of the pipelines with a depth of cover less than 80 cm are older pipelines. 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 larger than 1 meter. In the year 2012 and 2013 a sudden rise of the depth of

cover below 80 cm can be seen. This rise is caused by a new classification method of the cover depth by some EGIG members.

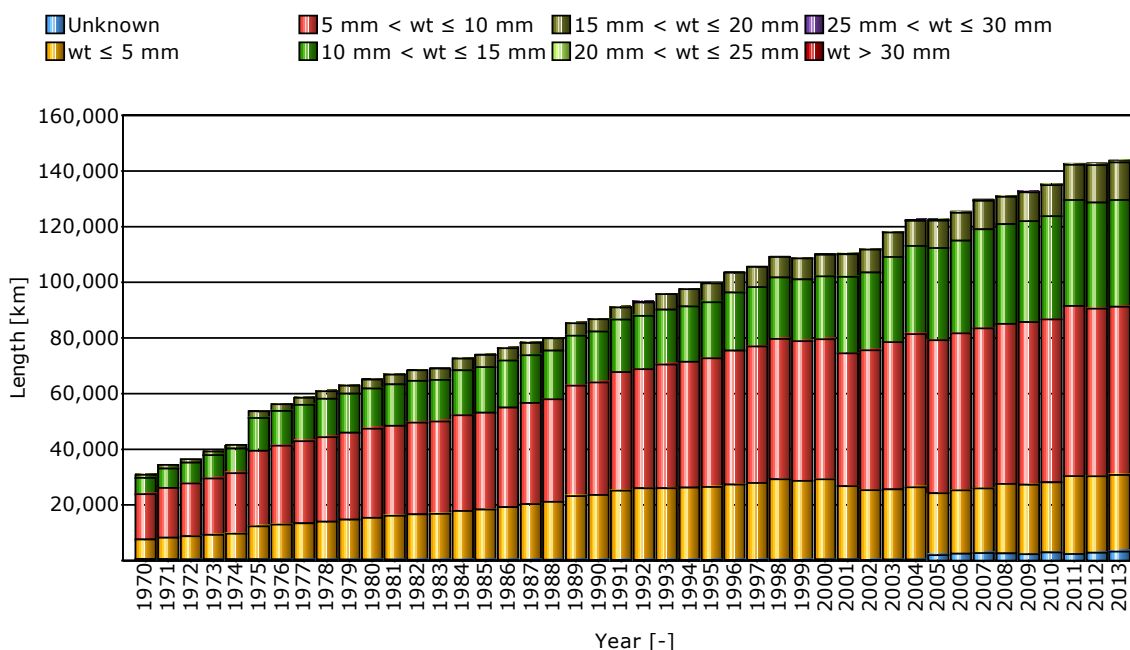


Figure 6: Total length per wall thickness (wt)

Figure 6 shows that the most commonly used wall thicknesses are 5 to 10 mm. The figure also shows that the proportion of every wall thickness class remains more or less constant over time, except for the ≤ 5 mm class, which has remained more or less constant in length since 2001.

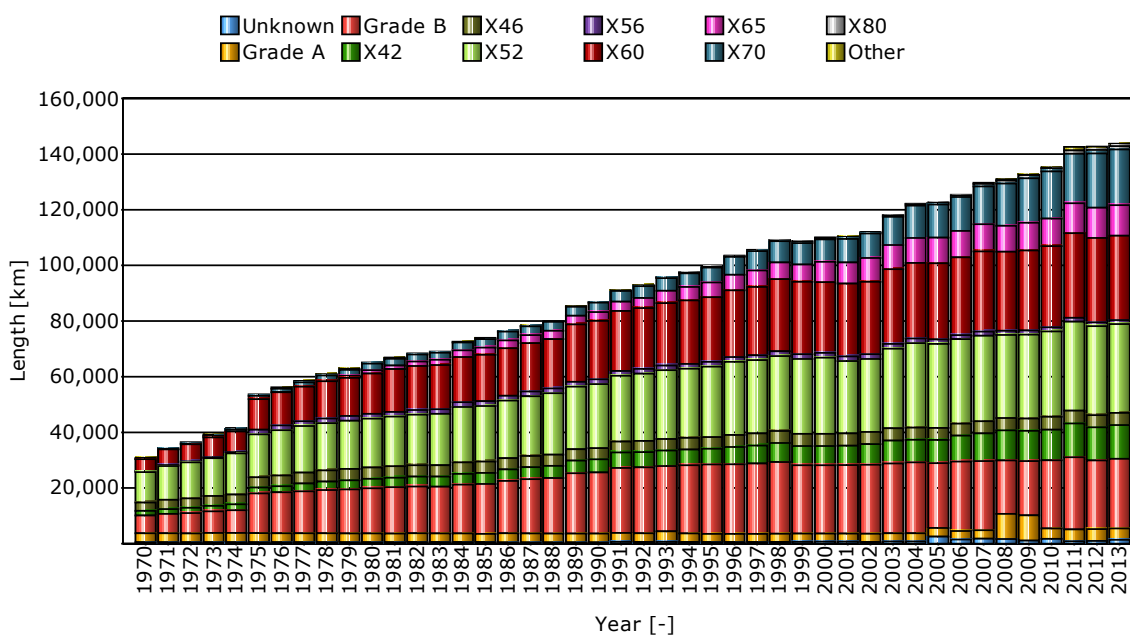


Figure 7: Total length per grade of material

Line pipe grade designations come from different specifications. The EGIG database is arranged according to equivalent API 5L [Ref 3] 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 of the pipe steel. Grade A was used for older pipelines. Grade B is still used for pipelines, especially for pipelines with relative small diameters.

Figure 7 demonstrates that three grades of material are predominant, namely: Grade B, X52 and X60. In recent years, the trend is to use high grade steel like X70.

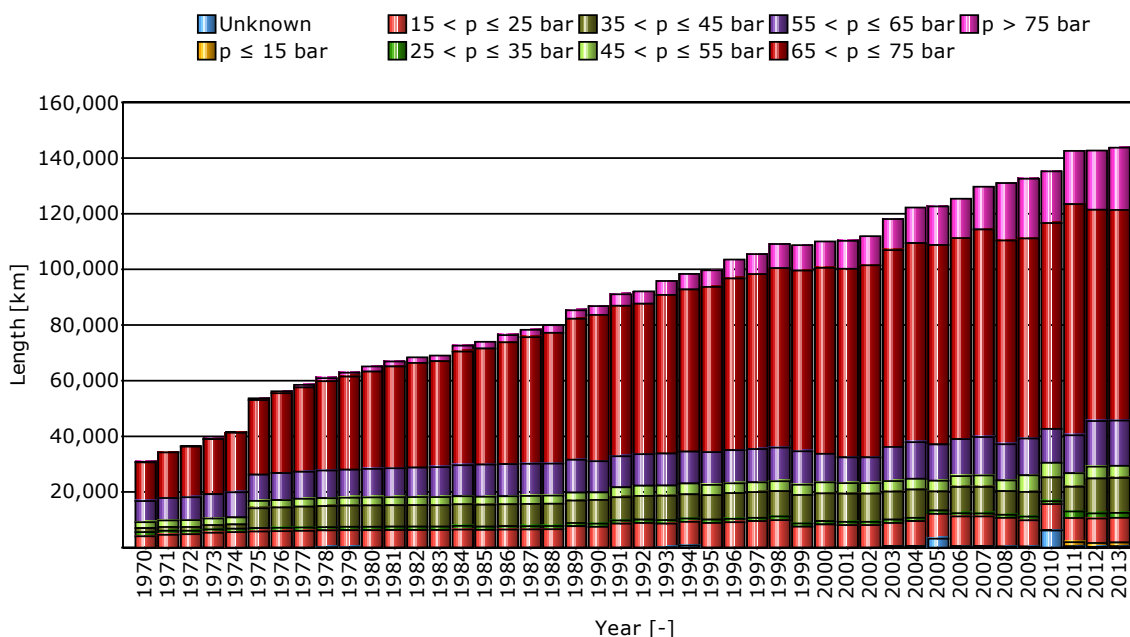


Figure 8: Total length per Maximum Operating Pressure (p)

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

3.2.2 Exposure

Figure 9 shows the increase of the exposure over the years. As discussed in paragraph 3.1 exposure is the length of a pipeline multiplied by its exposed duration and is expressed in kilometres-years [km·yr]. In 2013, the total system exposure was equal to 3,98 million km·yr.

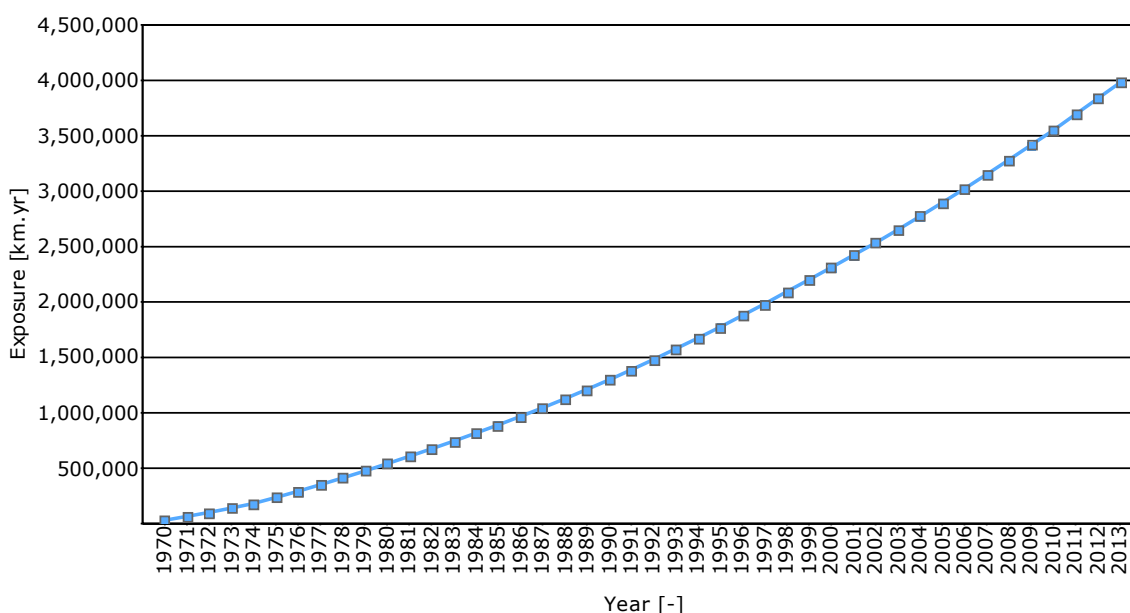


Figure 9: Evolution of the exposure

3.3 Failure frequencies analyses

This paragraph deals with the calculation of safety indicators, namely the primary and secondary failure frequencies. These calculations refer to three notions: the total system exposure, the partial system exposure and related number of incidents.

3.3.1 Number of incidents

In the eighth EGIG report, which covers the period 1970-2010, a total of 1,249 incidents were recorded.

In the last three years, 60 incidents were reported by the EGIG members, which brings the total number of incidents to 1,309 for the period 1970-2013. Figure 10 shows the number of incidents per year.

Figure 11 shows the cumulative number of incidents.

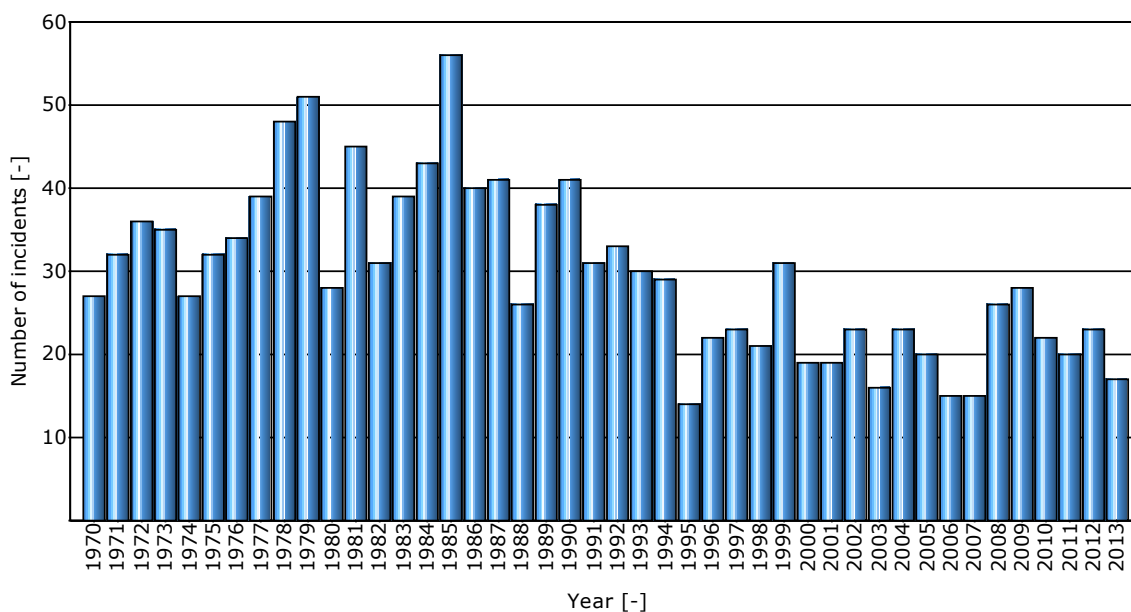


Figure 10: Annual number of incidents

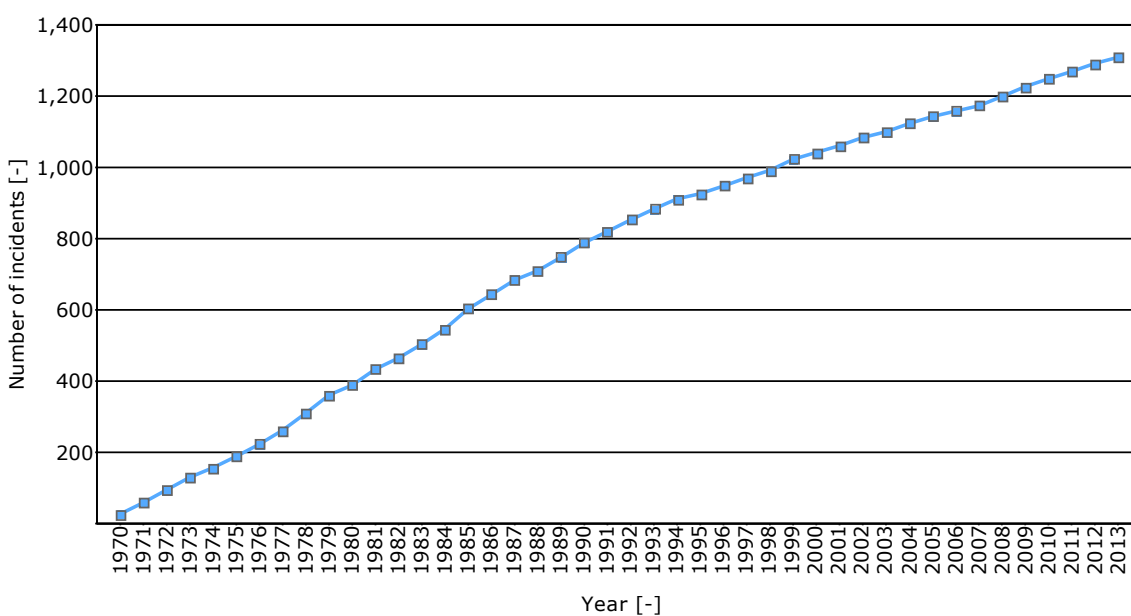


Figure 11: Cumulative number of incidents

3.3.2 Primary failure frequencies

As explained in paragraph 3.1, the primary failure frequency is the result of the number of incidents (Figure 11) within a period divided by the corresponding total system exposure (Figure 9). Depending on the period studied, 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 (1970-2013), the period corresponding to the 7th EGIG report (1970-2007) [Ref 1], the period of the 8th EGIG report (1970 -2010) [Ref 2] a period of the last 40, 30, 20, 10 and 5 years (2009-2013).

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 ·10 ⁶ km·yr	Primary failure frequency per 1,000 km·yr
1970 - 2007	7 th report 38 years	1173	3.15	0.372
1970 - 2010	8 th report 41 years	1249	3.55	0.351
1970 - 2013	9 th report 44 years	1309	3.98	0.329
1974 - 2013	40 years	1179	3.84	0.307
1984 - 2013	30 years	805	3.24	0.249
1994 - 2013	20 years	426	2.40	0.177
2004 - 2013	10 years	209	1.33	0.157
2009 - 2013	5 years	110	0.70	0.158

Table 1: Primary failure frequencies

In 2013, the primary failure frequency over the entire period (1970-2013) was equal to 0.33 per 1,000 km·yr. This is slightly lower than the failure frequency of 0.35 per 1,000 km·yr reported in the 8th EGIG report (1970-2010).

The primary failure frequency over the last five years was equal to 0.16 per 1,000 km·yr, showing an improved performance over recent years.

Figure 12 shows the evolution of the primary failure frequencies over the entire period and of the last five years.

Figure 12 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 0.33 per 1,000 km·yr in 2013. The 5-year moving average primary failure frequency decreased by a factor 5 (0.86 to 0.16 per 1,000 km·yr).

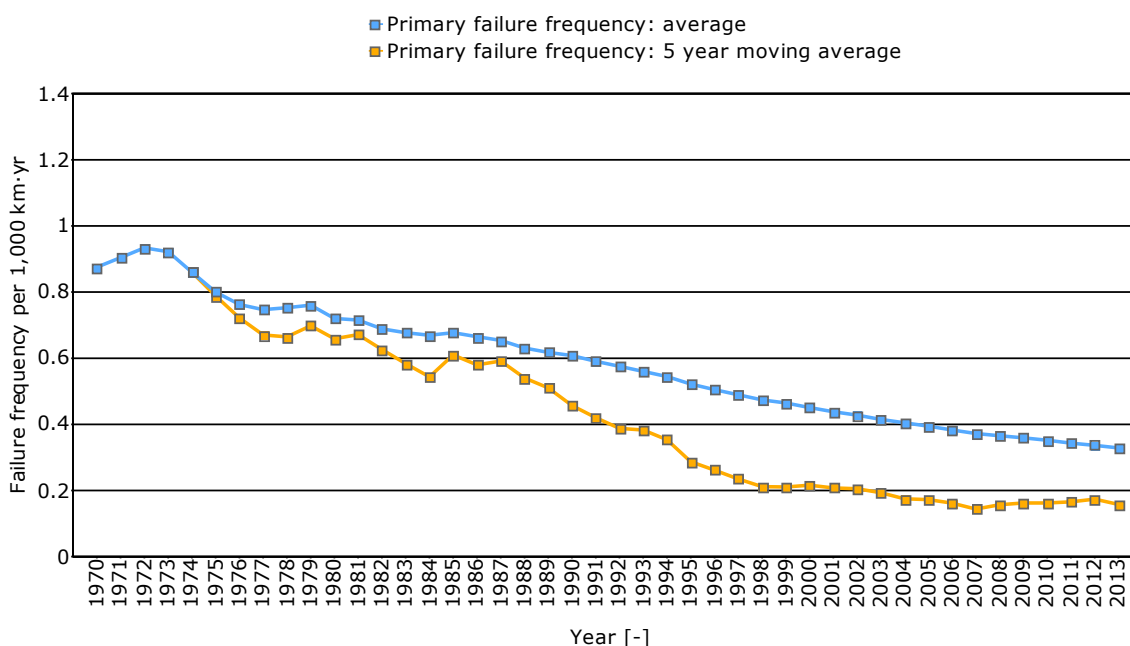


Figure 12: Primary failure frequencies

Not all leaks result in severe consequences. The EGIG database distinguishes between incidents with different leak size (ruptures, holes and pinholes/cracks). Figure 13 demonstrates the failure frequency per leak size for a 5-year moving average.

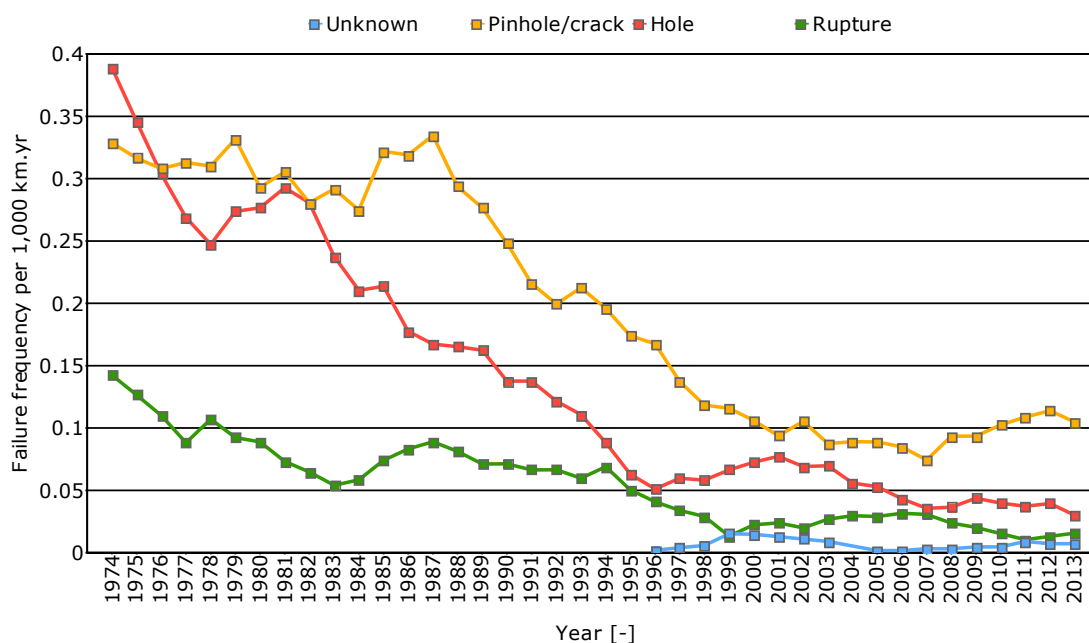


Figure 13: Primary (5-year moving average) failure frequency as a function of leak size

What can be seen from Figure 13 is 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. Around the year 2000 this trend seems to stabilise. For the year 2013 these values are given in Table 2.

Leak size	Primary 5 year mov. avg. failure frequency per 1,000 km·yr
Unknown	0.007
Pinhole/crack	0.105
Hole	0.030
Rupture	0.016

Table 2: Primary 5-year moving average failure frequency per leak size in 2013

Figure 14 and Table 3 demonstrates the relation between the primary failure frequency, the leak size and diameter of the pipeline.

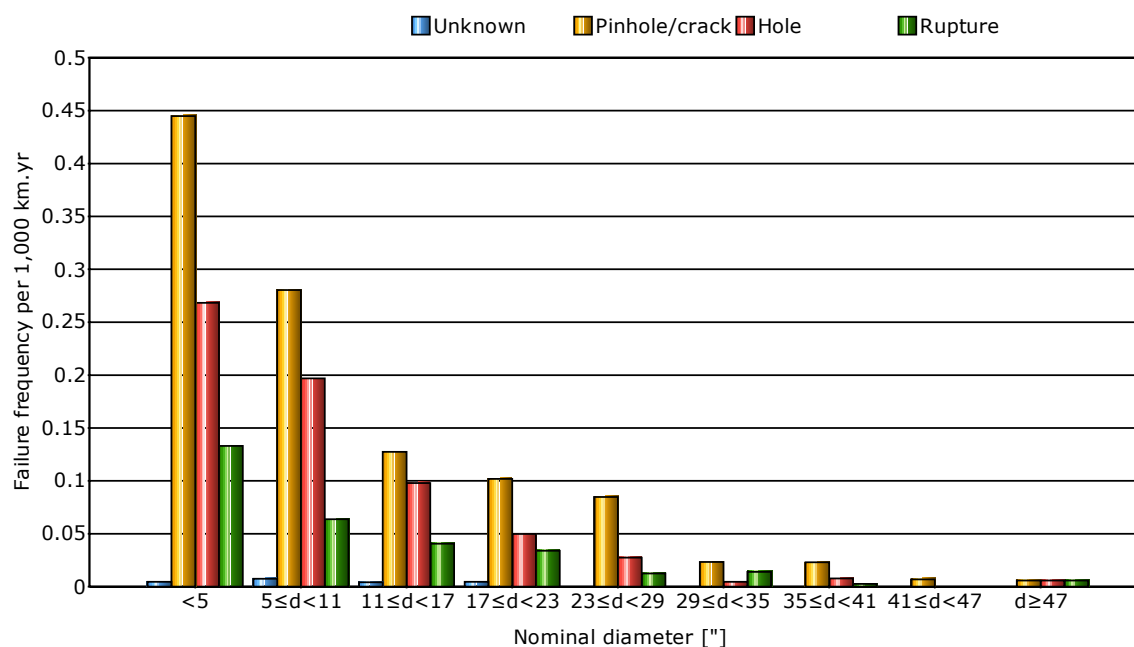


Figure 14: Primary failure frequency, pipeline diameter and size of leak (1970-2013)

Nominal diameter	System exposure ·10 ⁶ km·yr	Primary failure frequency per 1,000 km·yr			
		Unknown	Pinhole/crack	Hole	Rupture
diameter < 5"	0.436	0.005	0.445	0.268	0.133
5" ≤ diameter < 11"	1.066	0.008	0.280	0.197	0.064
11" ≤ diameter < 17"	0.714	0.004	0.127	0.098	0.041
17" ≤ diameter < 23"	0.442	0.005	0.102	0.050	0.034
23" ≤ diameter < 29"	0.401	0.000	0.085	0.027	0.012
29" ≤ diameter < 35"	0.214	0.000	0.023	0.005	0.014
35" ≤ diameter < 41"	0.389	0.000	0.023	0.008	0.003
41" ≤ diameter < 47"	0.146	0.000	0.007	0.000	0.000
diameter ≥ 47"	0.170	0.000	0.006	0.006	0.006

Table 3: Primary failure frequency, pipeline diameter and size of leak (1970-2013)

Figure 14 and Table 3 illustrate that ruptures mainly occurred at pipelines with smaller diameters and that failure frequencies decrease with increasing diameter.

In Figure 15 and Figure 16 the incident distributions per cause over the last 5 years and 10 years are given. In the period 2009-2013, corrosion and external interference incidents occur in about the same rate. However corrosion incidents tend to cause smaller leak sizes (see Figure 19 and Figure 20).

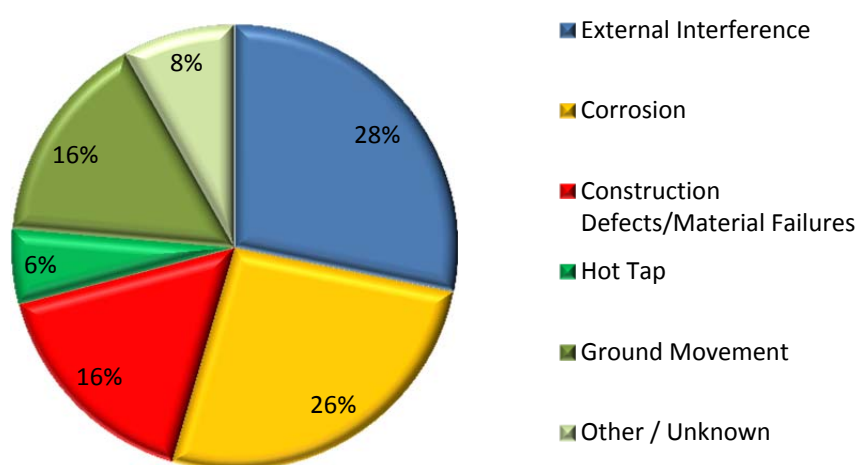


Figure 15: Distribution of incidents (2009–2013)

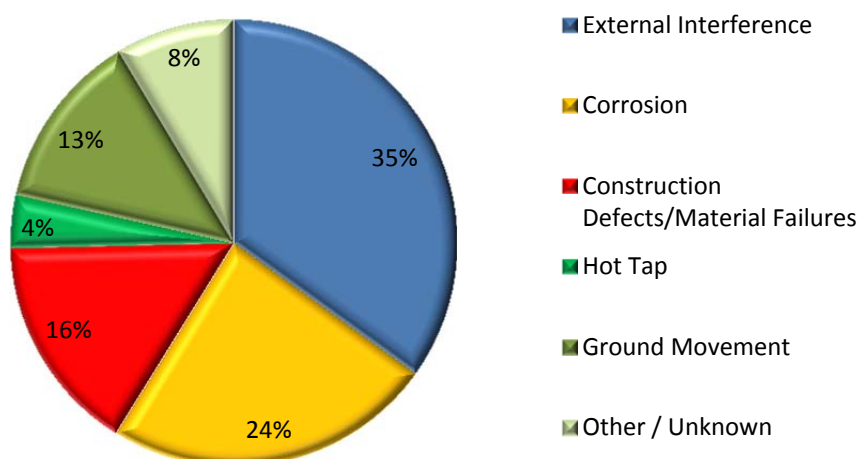


Figure 16: Distribution of incidents (2004-2013)

Figure 17, Figure 18 and Table 4 give the primary failure frequencies for the entire period (up to the year) and for the last five years moving average per cause.

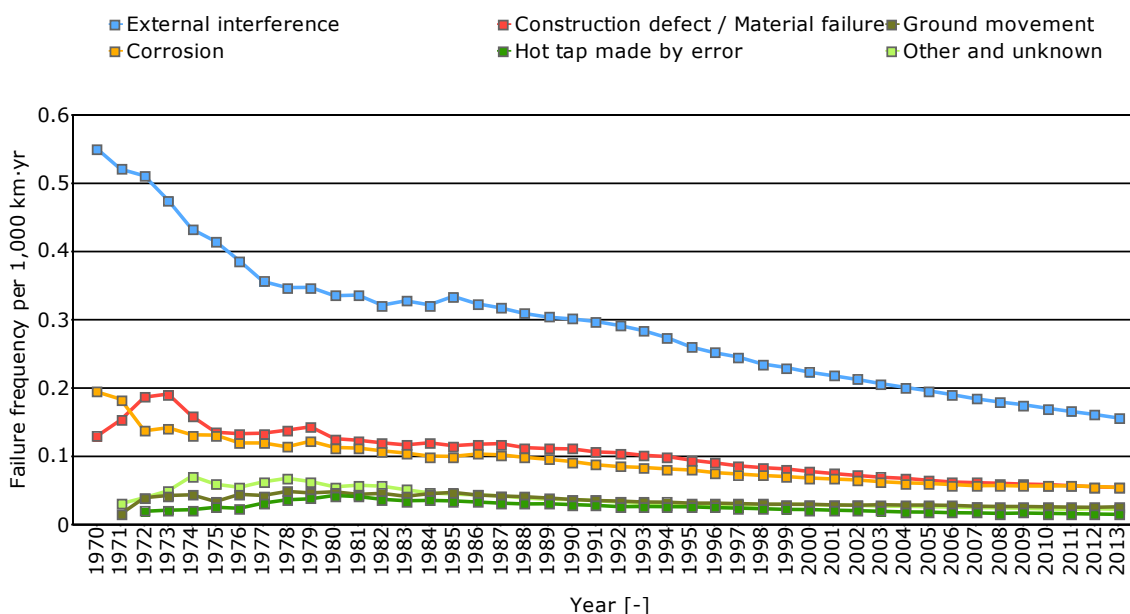


Figure 17: Primary failure frequencies per cause (up to the year)

Figure 17 illustrates the decreasing failure frequencies over the years. This may be explained by technological developments, such as: welding, inspection, condition monitoring using in-line inspection and improved procedures for damage prevention and detection.

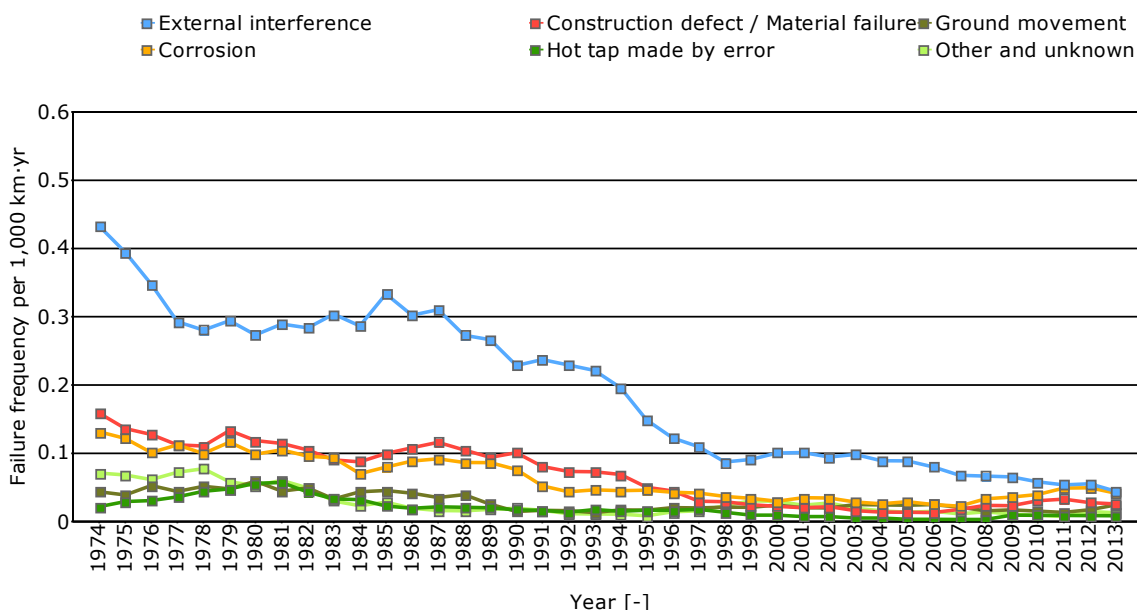


Figure 18: Primary failure frequencies per cause (5-year moving average)

As far as the cause external interference is concerned, its associated primary failure frequency over the period 1970-2013 decreased to 0.16 per 1,000 km·yr while the 5-year moving average has levelled off at around 0.05 per 1,000 km·yr.

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.

External interference and corrosion are in the period 2009 to 2013 the main causes of incidents.

Cause	Primary Failure frequency		
	1970-2013 per 1,000 km·yr	2004-2013 per 1,000 km·yr	2009-2013 per 1,000 km·yr
External interference	0.156	0.055	0.044
Corrosion	0.055	0.038	0.042
Construction defect / Material failure	0.055	0.025	0.026
Hot tap made by error	0.015	0.006	0.009
Ground movement	0.026	0.020	0.024

Table 4: Primary failure frequencies per cause (confidence intervals are given in APPENDIX 1)

To demonstrate failure frequencies over a more recent period, EGIG also presents, in addition to the frequencies for the whole period, frequencies over a time span of the last 5 and 10 years (see Table 4).

Figure 19 (period 1970-2013) and Figure 20 (period 2004-2013) show the failure frequency per leak size and per incident cause. Although the failure frequency decreased over the years the

general trends 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 19 and Figure 20 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 the distribution of normal corrosion incidents.

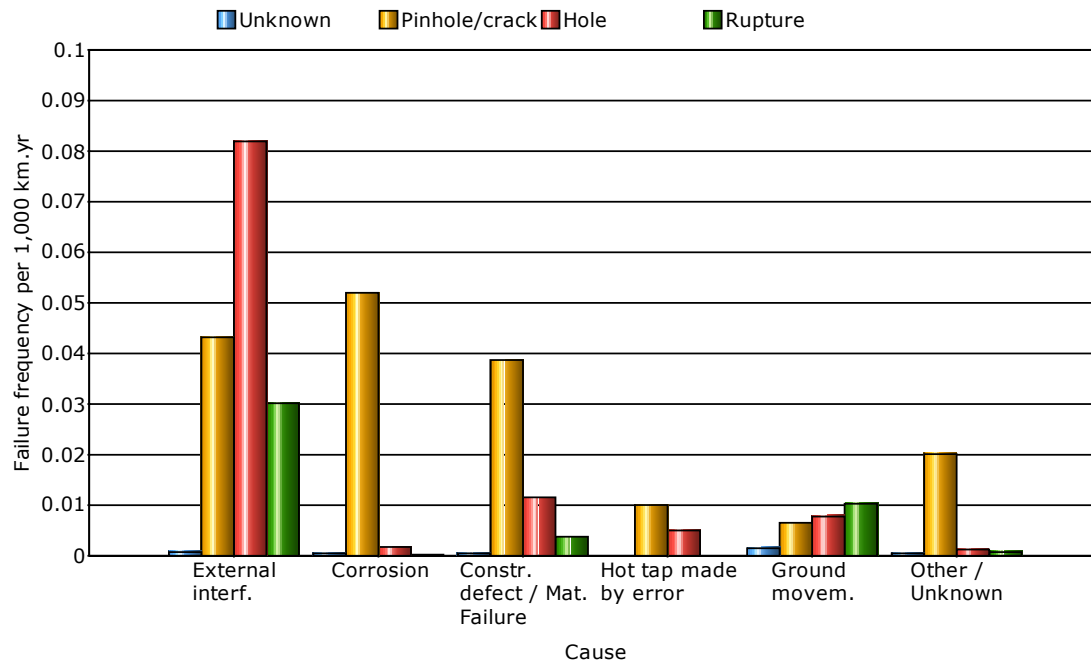


Figure 19: Relation primary failure frequency, cause and size of leak (1970-2013)

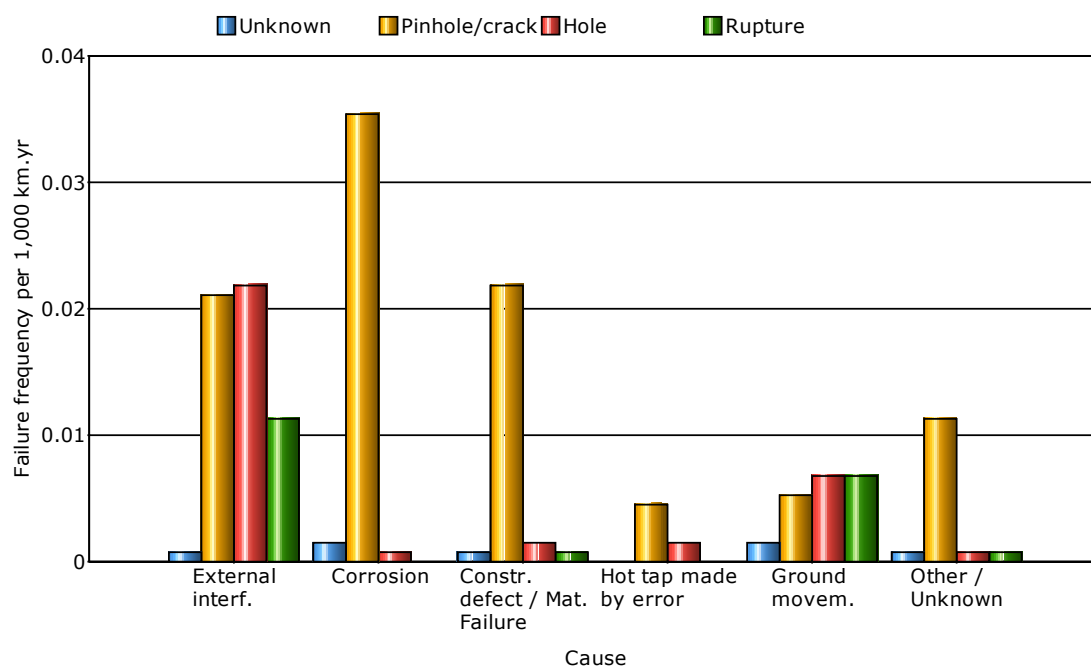


Figure 20: Relation primary failure frequency, cause and size of leak (2004-2013)

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
Unknown	0.001	0.002	0.001	0	0.002	0.001
Pinhole/Crack	0.021	0.035	0.022	0.005	0.005	0.011
Hole	0.022	0.001	0.002	0.002	0.007	0.001
Rupture	0.011	0	0.001	0	0.007	0.001

Table 5: Primary failure frequency, cause and size of leak (2004 -2013)

3.3.3 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 frequencies of the causes and consequences of the incidents. The calculations are performed for the whole database and for a more recent time period of the last 10 years (2004-2013).

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 or unknown” causes, other more relevant considerations are reported.

3.3.3.1 Relation between external interference, size of leak and design parameter

Figure 21 to Figure 32 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 each design parameter, four graphs are presented: the first two graphs present the failure frequency for every parameter class, one for the period 1970-2013, the other for the period 2004-2013. The 3rd and 4th graph give a further breakdown of the failure frequencies per size of leak.

Although the graphs are presented separately it must be noticed that the design parameters are correlated. No quantitative correlations between parameters have been studied.

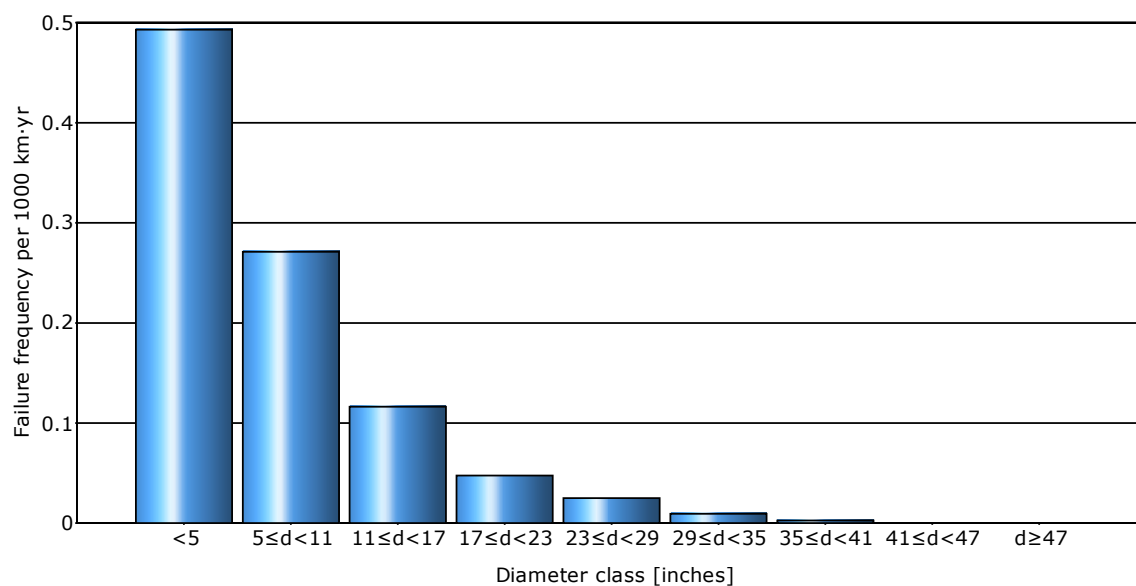


Figure 21: Relation external interference and diameter (d) (1970-2013)

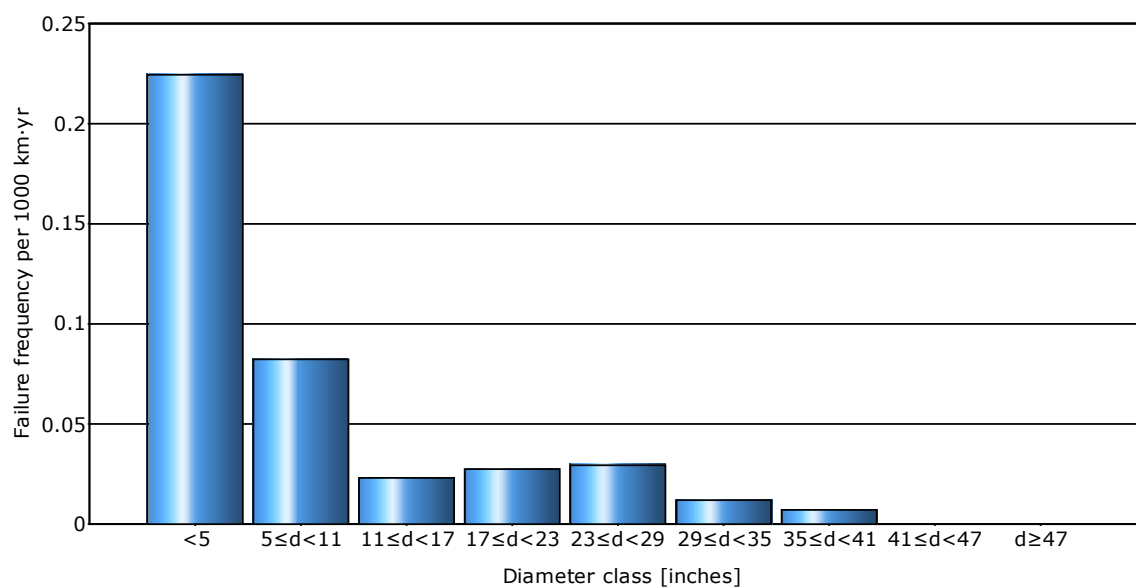


Figure 22: Relation external interference and diameter (d) (2004-2013)

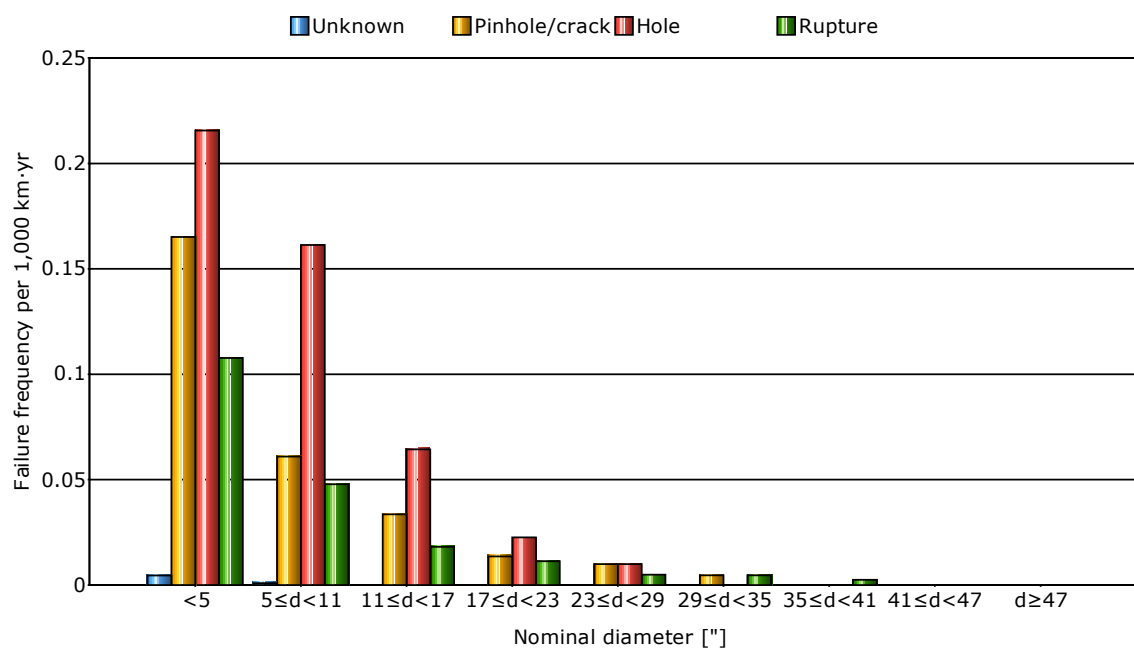


Figure 23: Relation external interference, size of leak and diameter (d) (1970-2013)

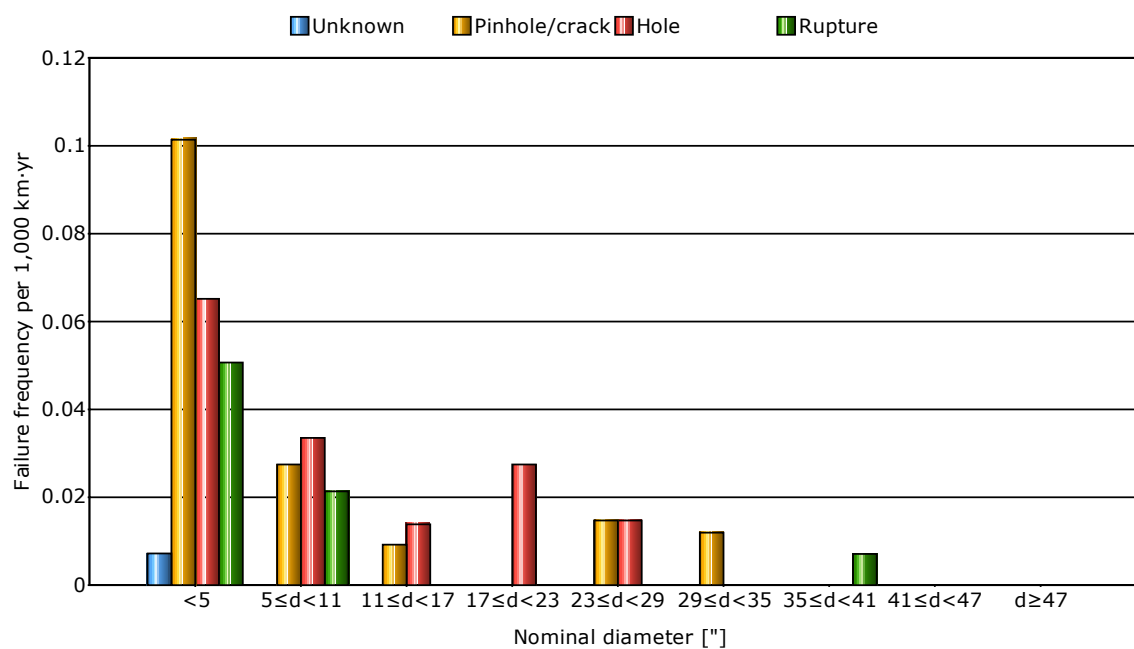


Figure 24: Relation external interference, size of leak and diameter (d) (2004-2013)

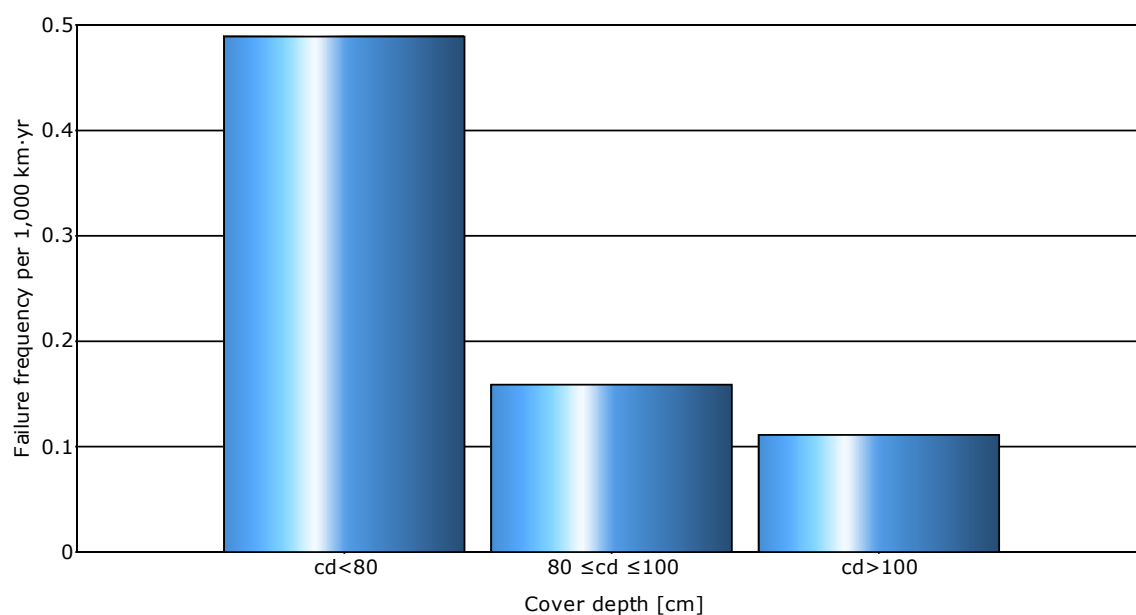


Figure 25: Relation external interference and depth of cover (cd) (1970-2013)

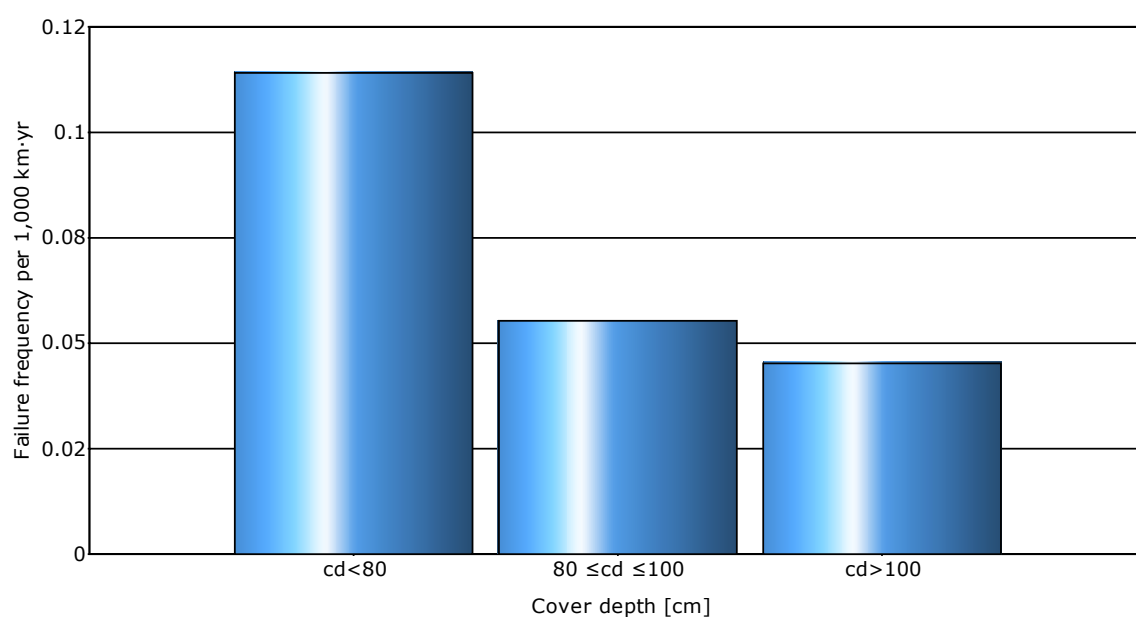


Figure 26: Relation external interference and depth of cover (cd) (2004-2013)

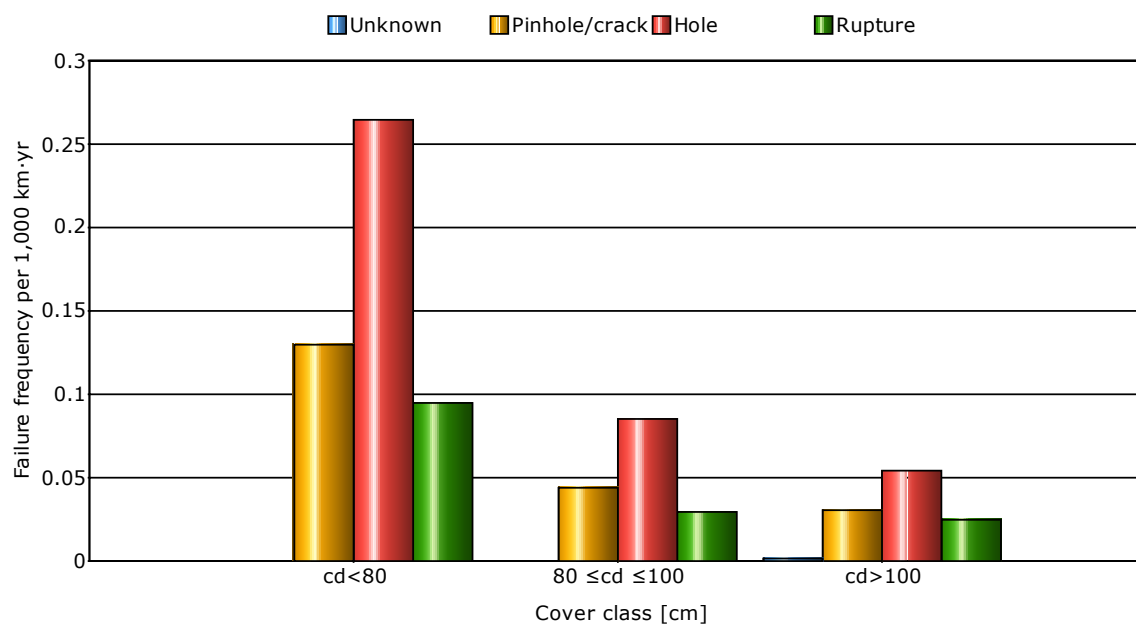


Figure 27: Relation external interference, size of leak and depth of cover (cd) (1970-2013)

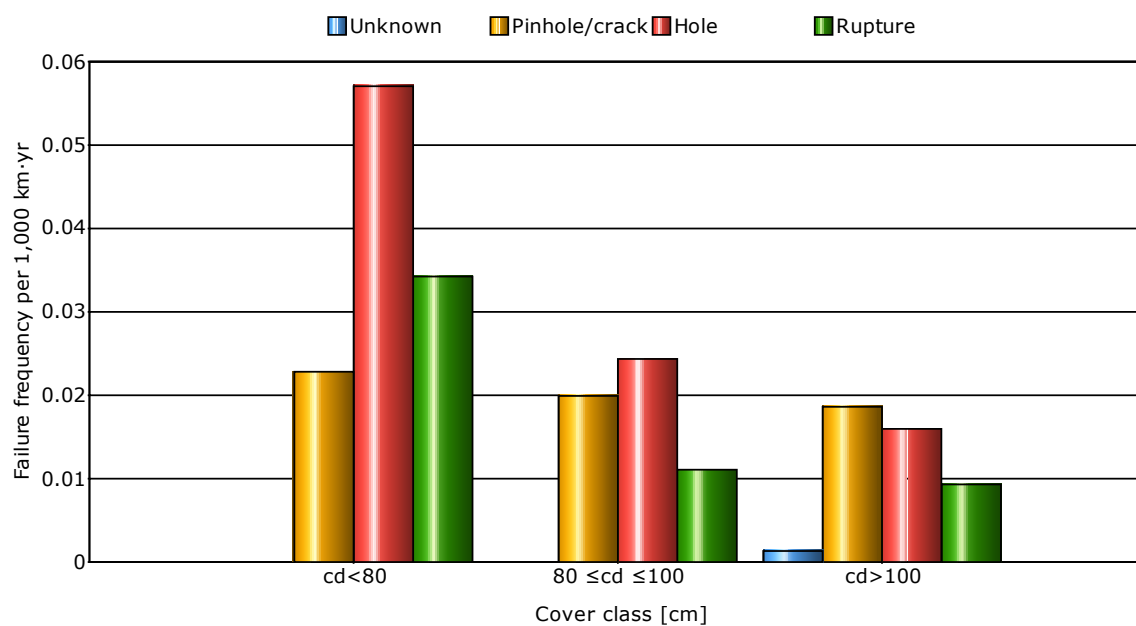


Figure 28: Relation external interference, size of leak and depth of cover (cd) (2004-2013)

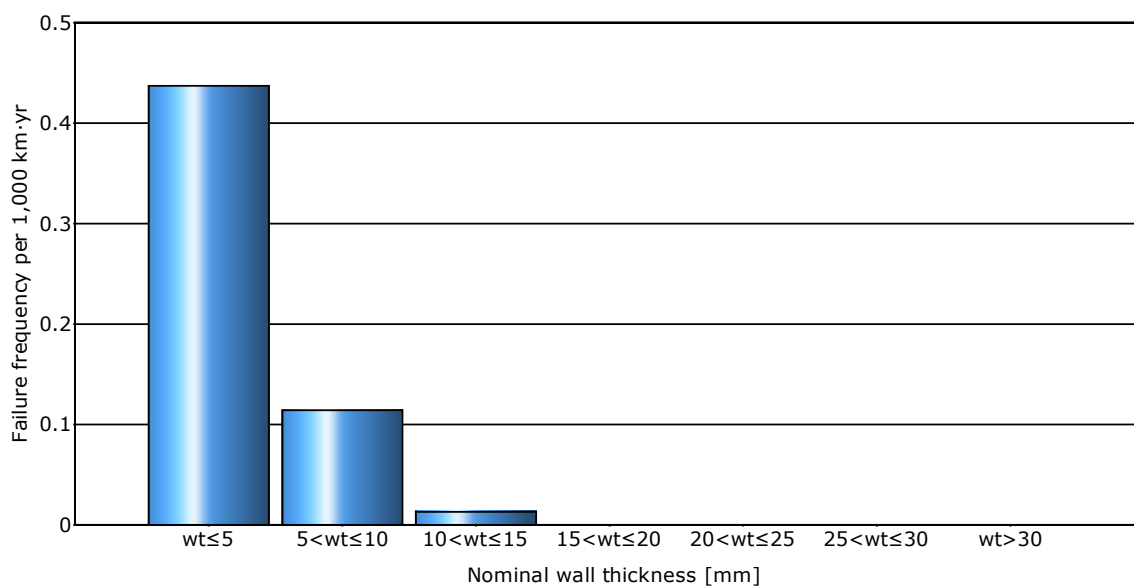


Figure 29: Relation external interference and wall thickness (wt) (1970-2013)

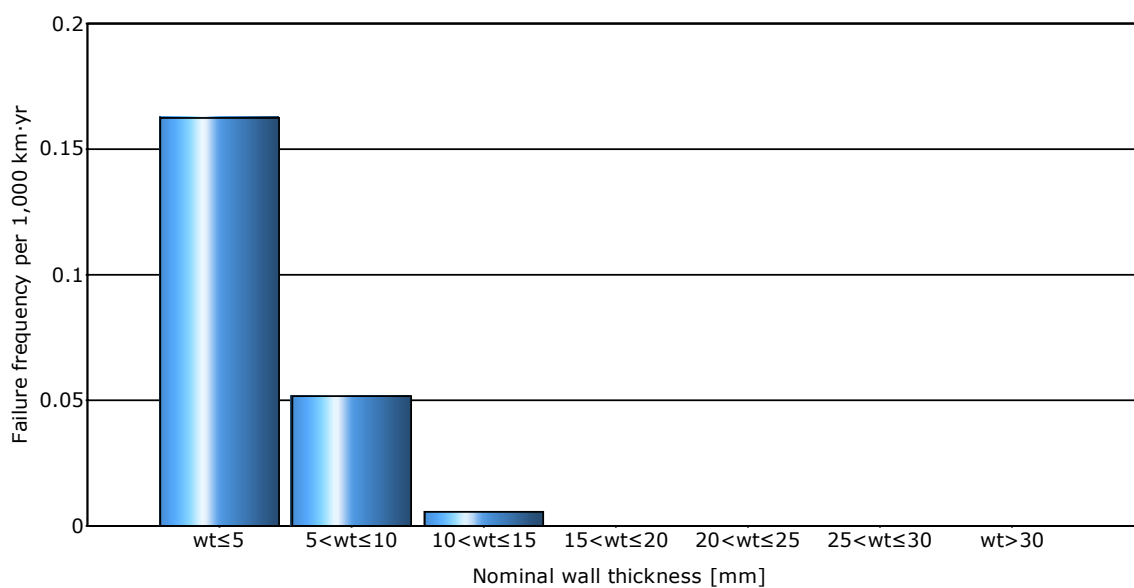


Figure 30: Relation external interference and wall thickness (wt) (2004-2013)

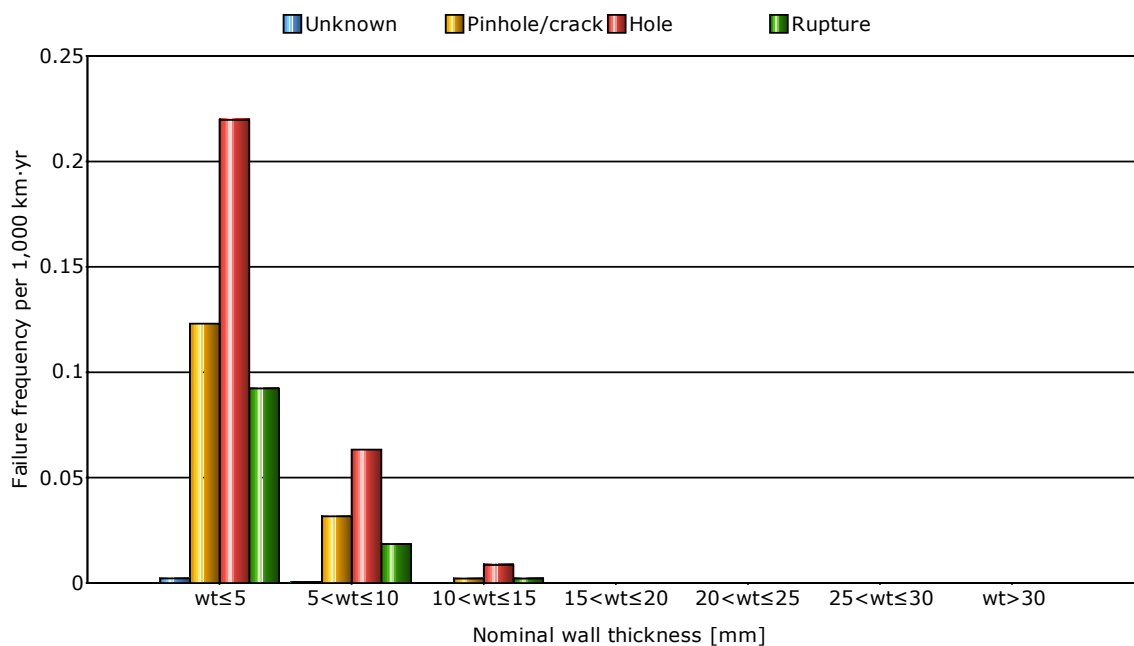


Figure 31: Relation external interference, size of leak and wall thickness (wt) (1970-2013)

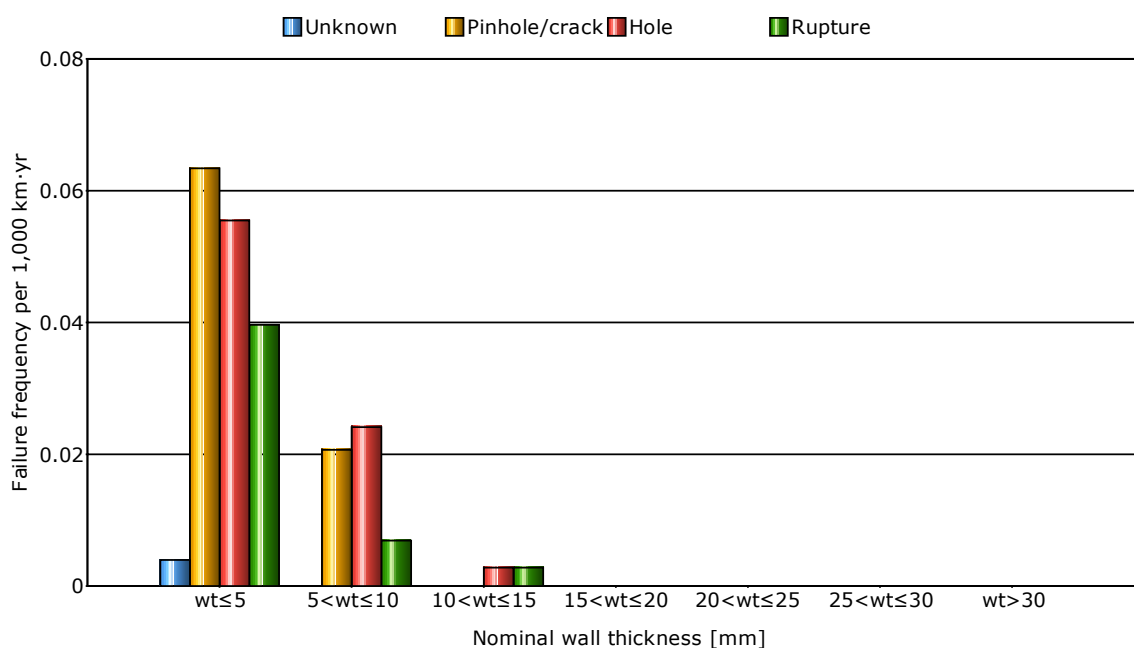


Figure 32: Relation external interference, size of leak and wall thickness (wt) (2004-2013)

From these figures, some general conclusions can be drawn:

- Large diameter pipelines are less vulnerable to external interferences than smaller diameter pipelines (Figure 21 and Figure 22). 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 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 primary failure frequency (Figure 25 and Figure 26).
- Pipelines with a larger wall thickness have a lower failure frequency of external interference (Figure 29 and Figure 30).

3.3.3.2 Relation between corrosion, size of leak and design parameter

Figure 33 to Figure 43 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, four graphs are constructed: the first two graphs present the failure frequency for every parameter class, one for the period 1970-2013, the other for the period 2004-2013. The 3rd and 4th graph give a further breakdown of the failure frequency per size of leak.

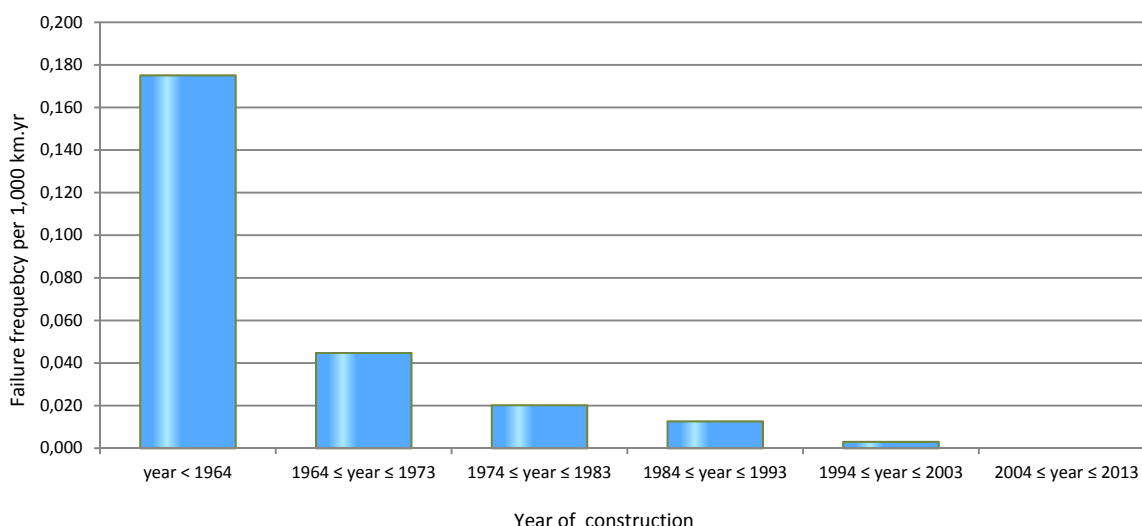


Figure 33: Relation corrosion and year of construction (1970-2013)

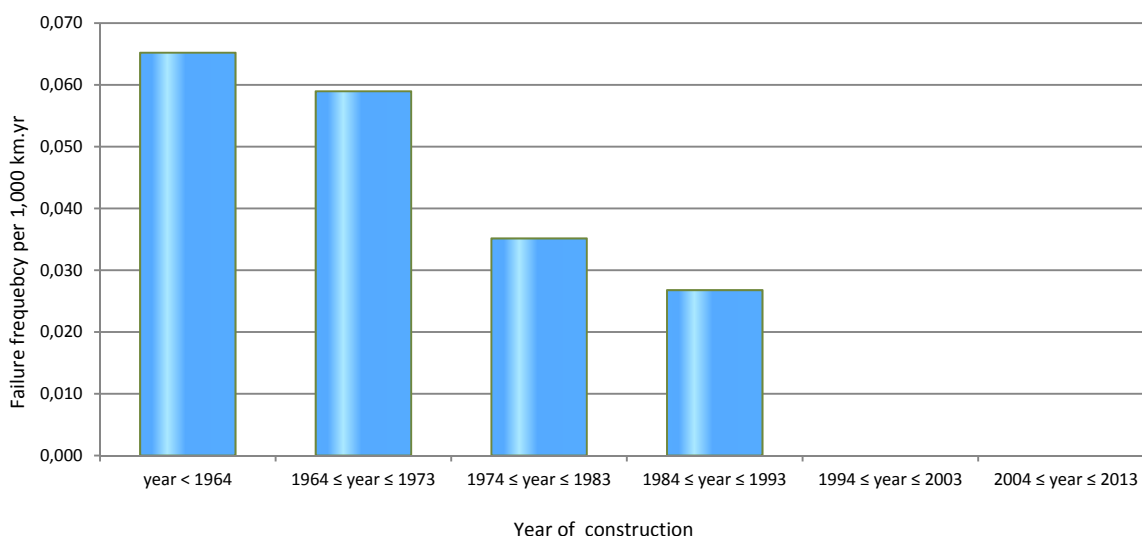


Figure 34: Relation corrosion and year of construction (2004-2013)

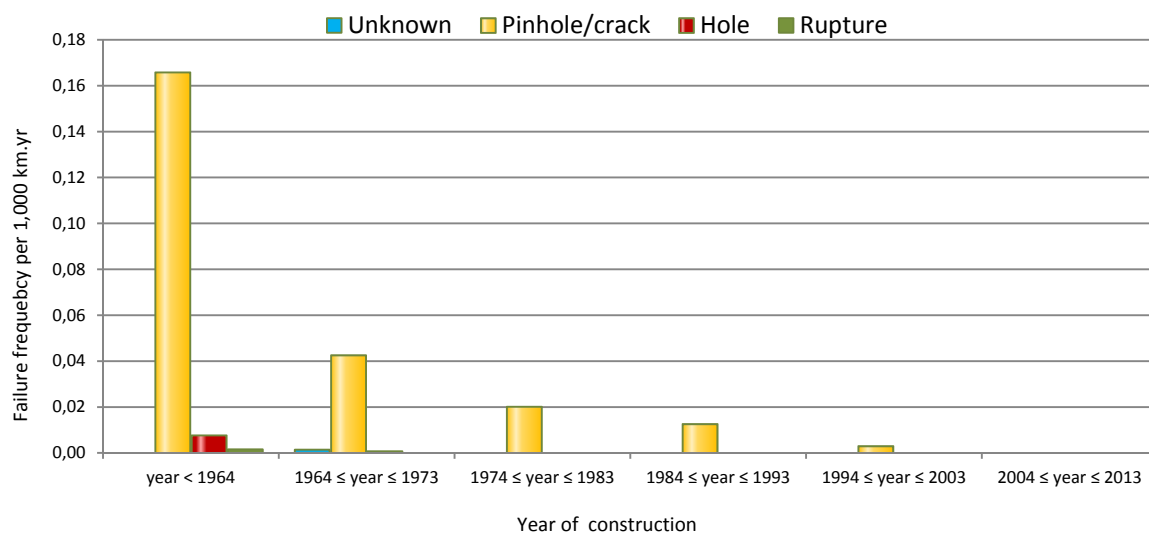


Figure 35: Relation corrosion, size of leak and year of construction (1970-2013)

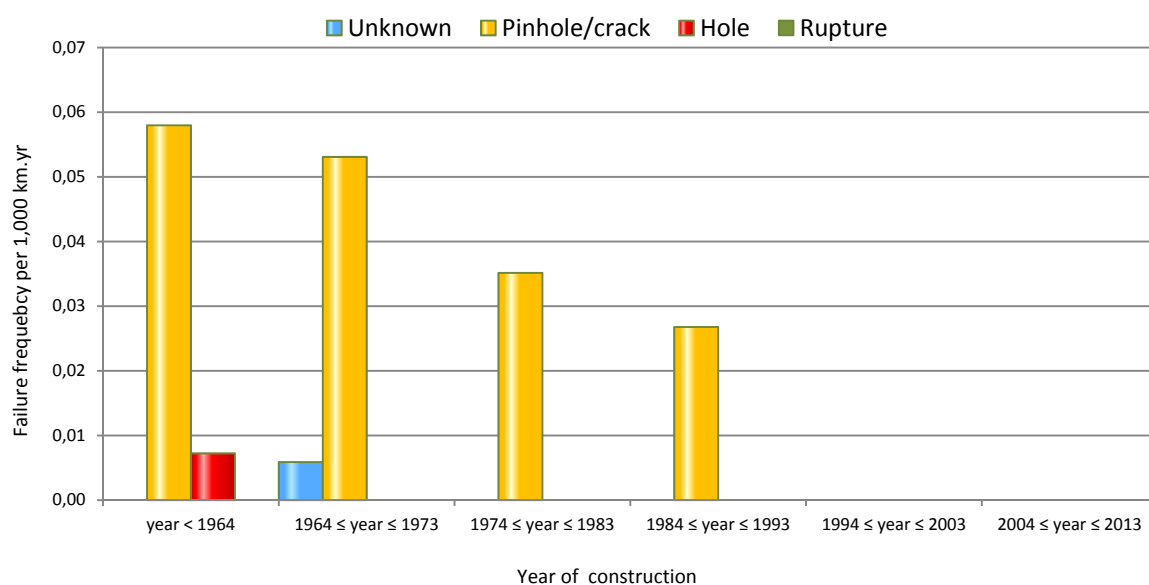


Figure 36: Relation corrosion, size of leak and year of construction (2004-2013)

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

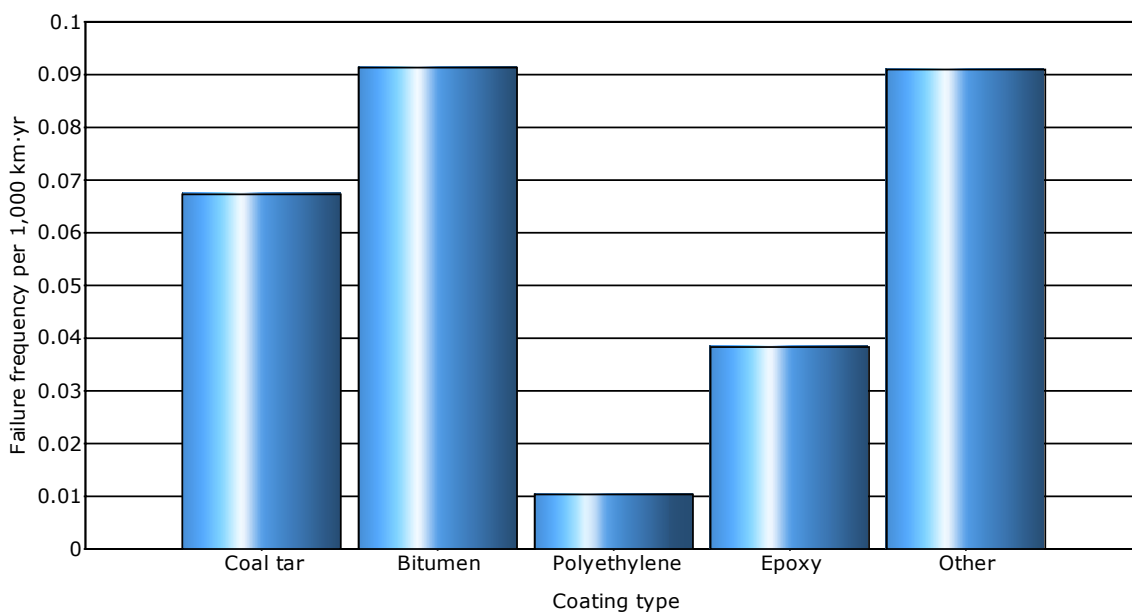


Figure 37: Relation corrosion and most common type of coating (1970-2013)

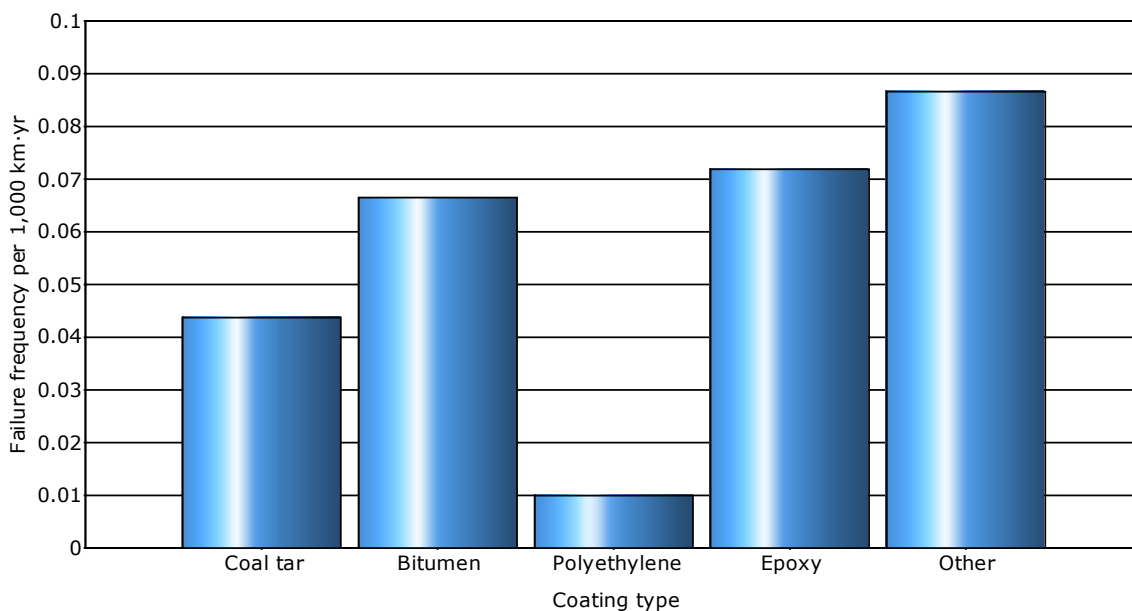


Figure 38: Relation corrosion and most common type of coating (2004-2013)

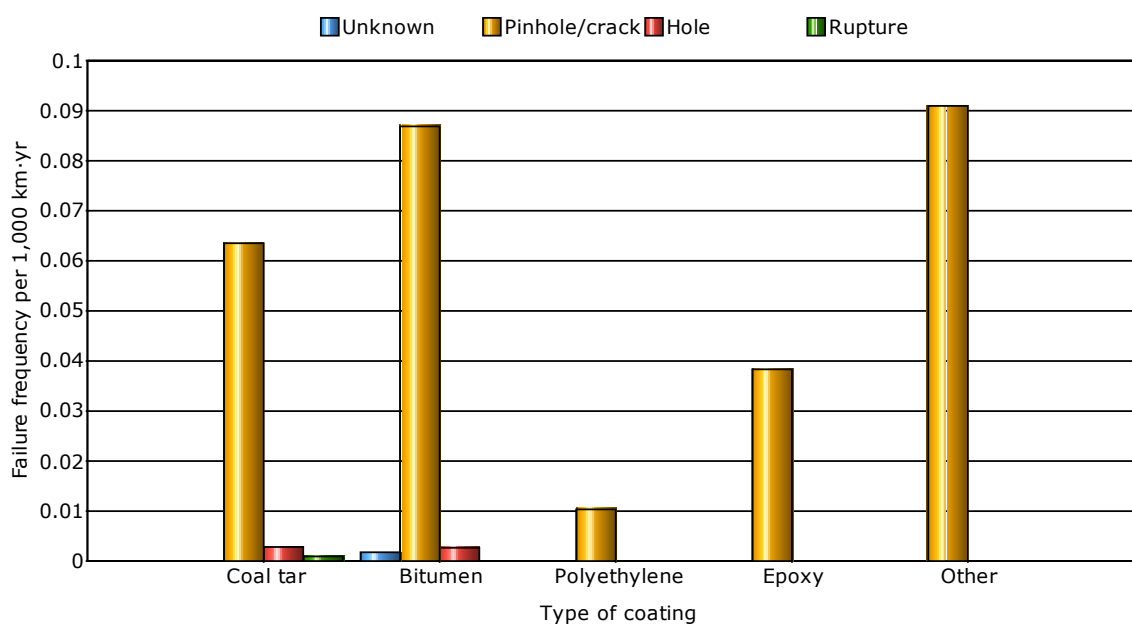


Figure 39: Relation corrosion, size of leak and most common type of coating (1970-2013)

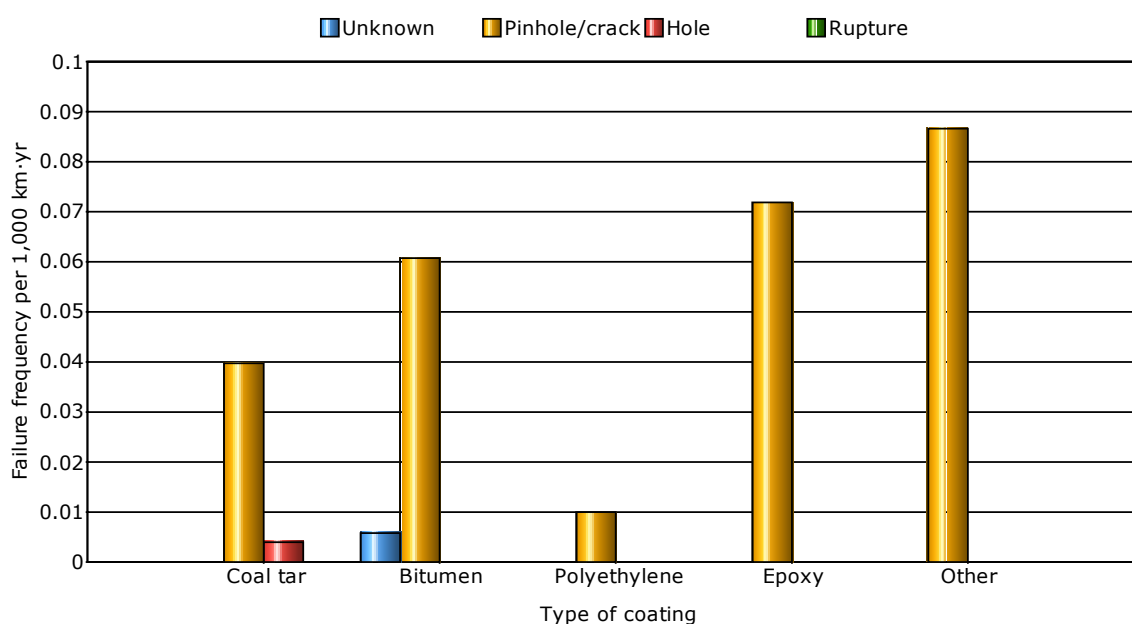


Figure 40: Relation corrosion, size of leak and most common type of coating (2004-2013)

Different protective measures are undertaken by pipeline owners to overcome the problem of 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.

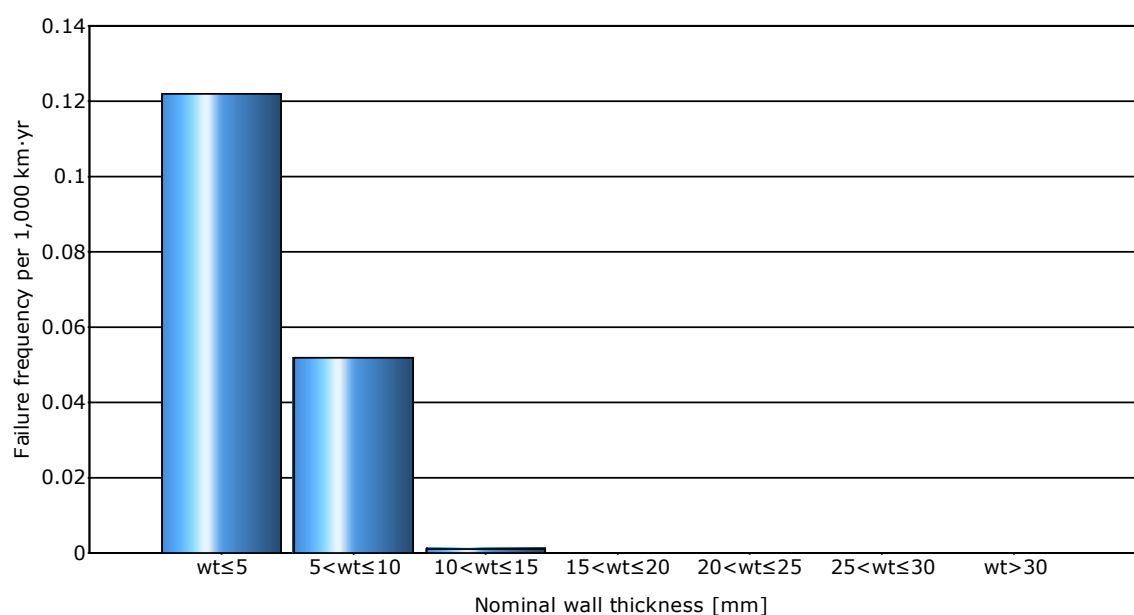


Figure 41: Relation corrosion and wall thickness (wt) (1970-2013)

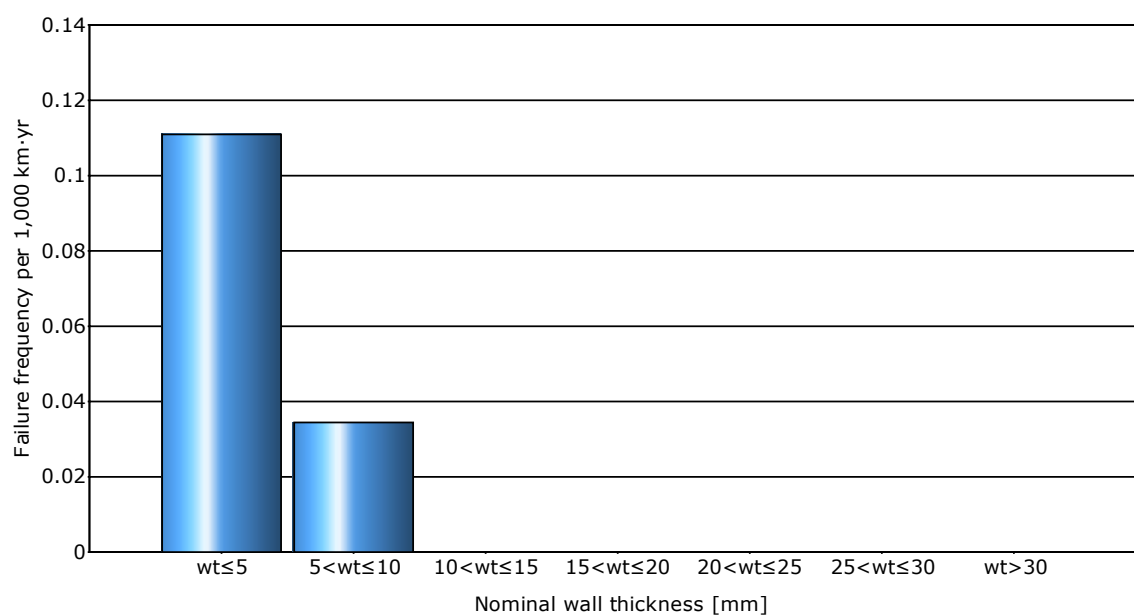


Figure 42: Relation corrosion and wall thickness (wt) (2004-2013)

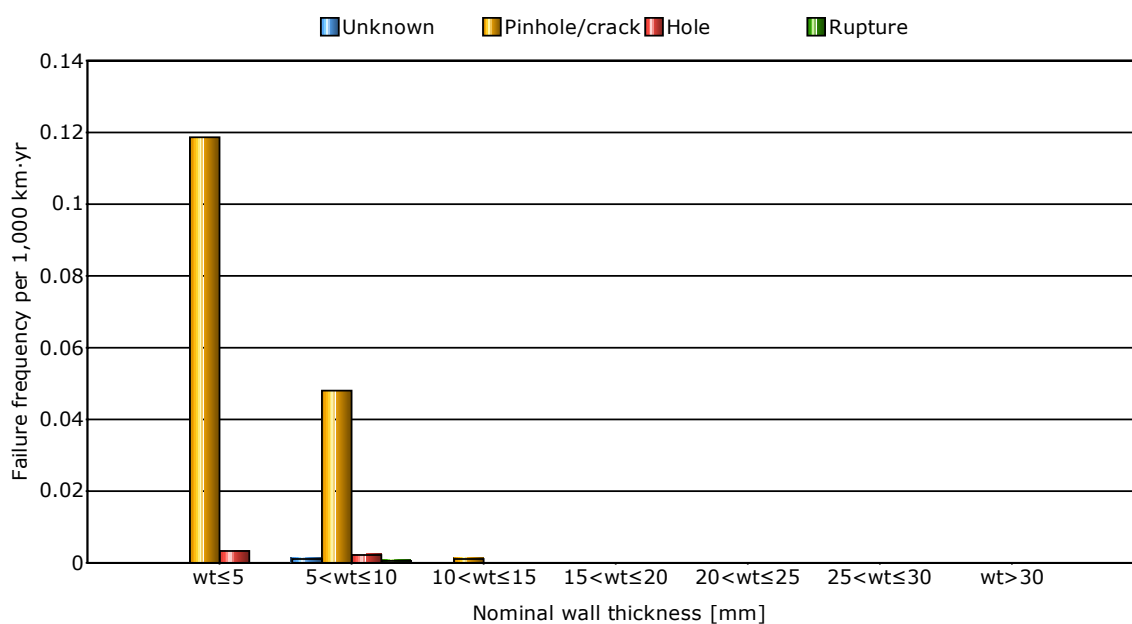


Figure 43: Relation corrosion, size of leak and wall thickness (wt) (1970-2013)

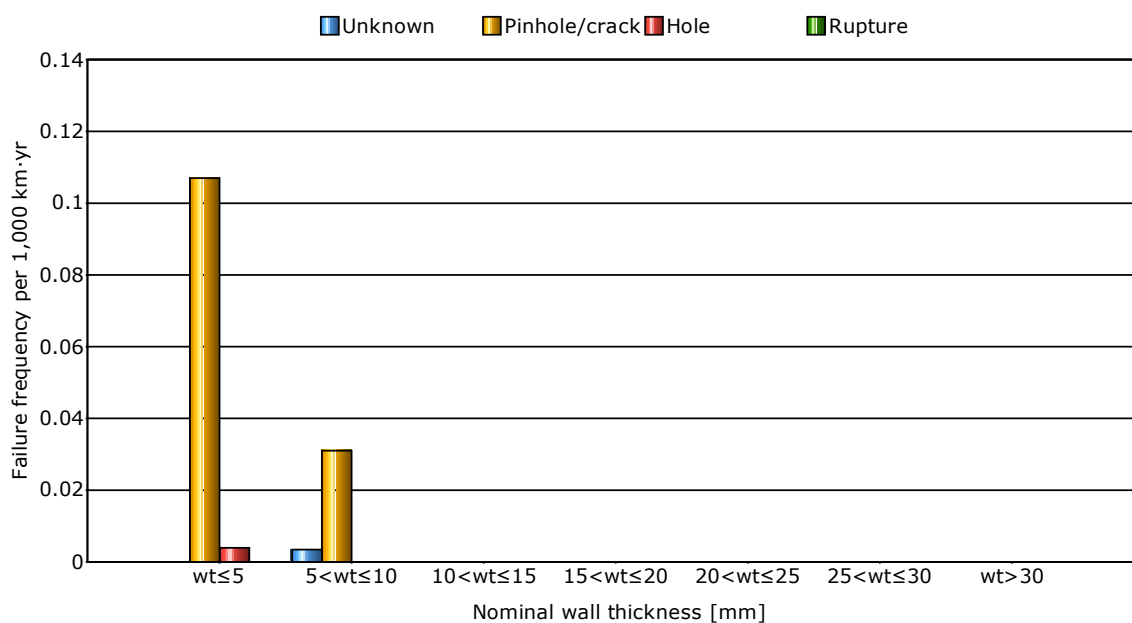


Figure 44: Relation corrosion, size of leak and wall thickness (wt) (2004-2013)

From these figures some general conclusions can be drawn:

- The failure frequency decrease with increasing year of construction.
- The failure frequency decrease 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. Different protective measures are undertaken by pipeline owners to overcome the problem of 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.
- 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)

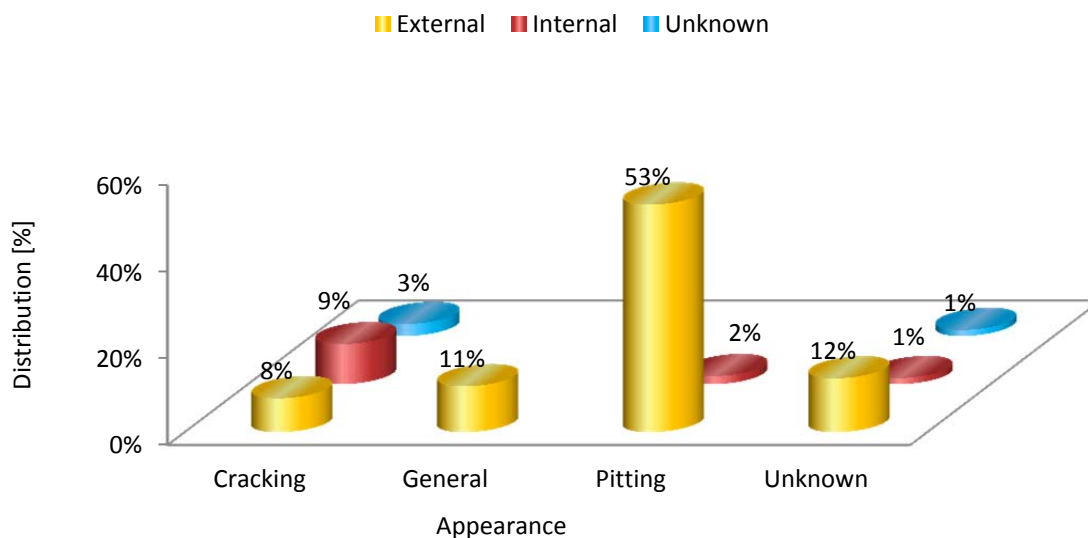


Figure 45: Breakdown of corrosion incidents on basis of location and appearance (1970-2013)

Figure 45 demonstrates that pitting is the most common form of corrosion. Almost all corrosion incidents with pitting occur on the external surface of the pipelines.

General corrosion is the second corrosion form to be found on the external surface of the pipelines. Uniform corrosion, also known as general corrosion, takes place evenly over the surface of the metal.

Figure 45 shows that corrosion incidents, where cracking was involved, occur in about the same percentage on the external and inner surface of the pipelines.

3.3.3.3 *Relation between construction defect / material failures, size of leak and design parameter*

EGIG recognizes construction defects / material failures as one of the causes of pipeline incidents. During the last ten years, they have represented about 16% of the pipeline incidents and are ranked third in the causes of incidents (see Figure 15 and Figure 16).

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

Figure 46 to Figure 49 show the failure frequencies for the incident cause “construction defect” for different classes of construction year and leak sizes. The first two graphs present the failure frequency per class of construction year, one for the period 1970-2013, the other for the period 2004-2013. The 3rd and 4th graph give a further breakdown of the failure frequency per size of leak.

From these figures, some general conclusions can be drawn: Failure frequencies for “construction defect” generally decrease with increasing year of construction. New pipelines are less vulnerable to construction defects due to technical improvements. This phenomenon has also been observed in the ageing analysis (see paragraph 3.4.1).

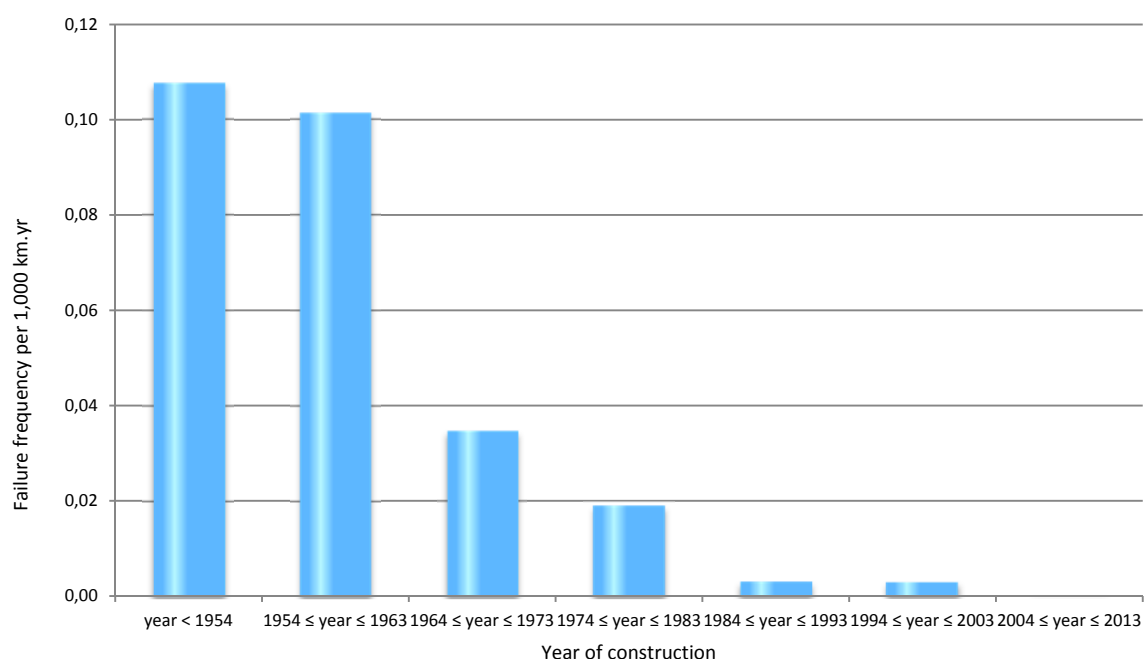


Figure 46: Relation construction defect and year of construction (yr) (1970-2013)

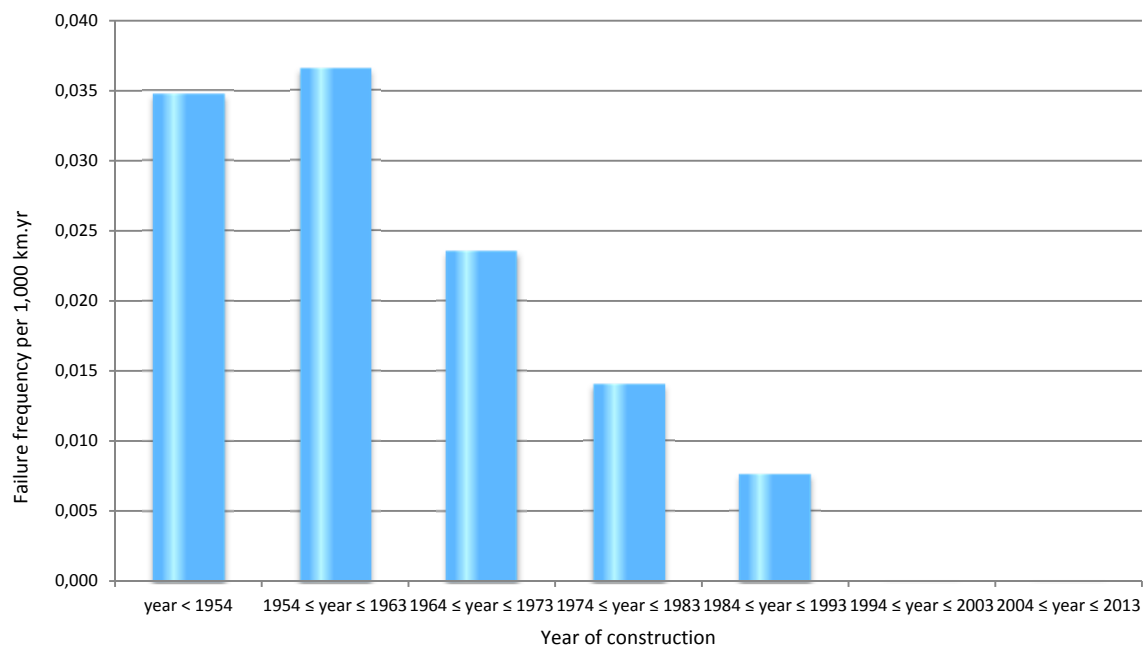


Figure 47: Relation construction defect and year of construction (yr) (2004-2013)

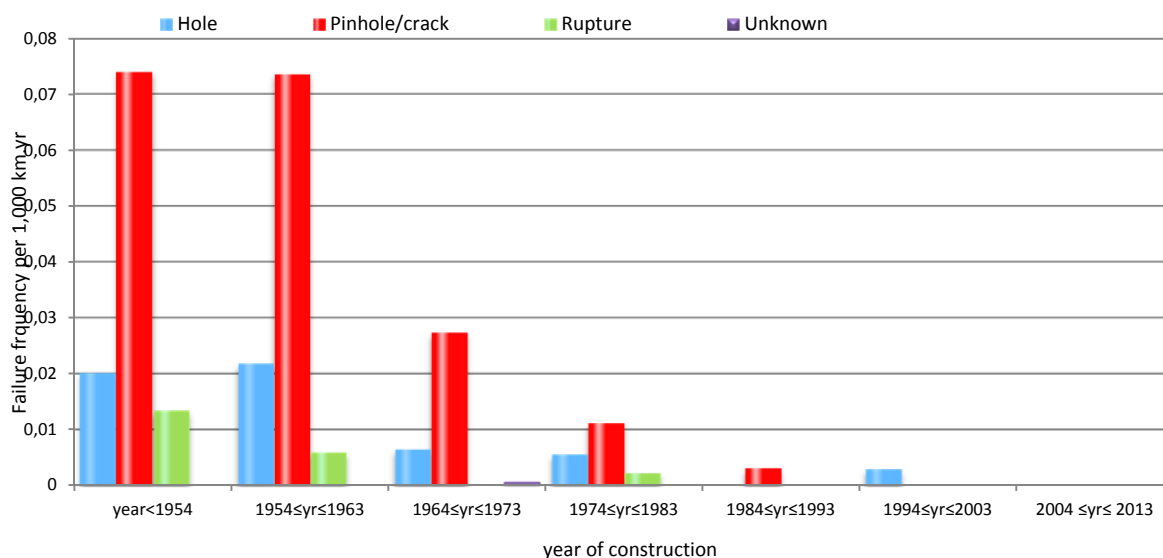


Figure 48: Relation construction defect, size of leak and year of construction (yr) (1970-2013)

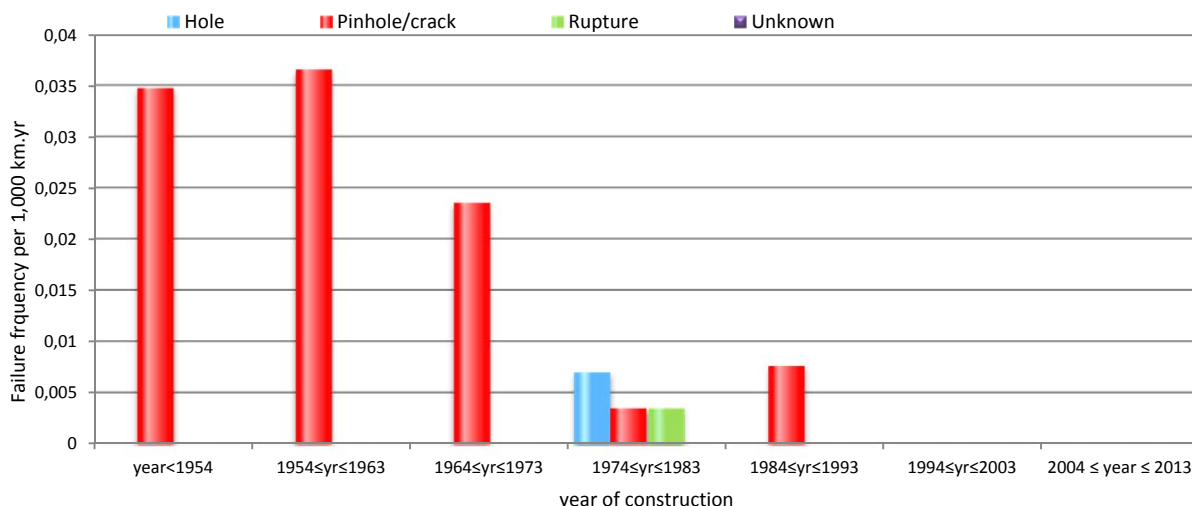


Figure 49: Relation construction defect, size of leak and year of construction (yr) (2004-2013)

Figure 50 to Figure 53 show the failure frequencies for the incident cause “material failure” for different classes of material grade and leak sizes. The first two graphs present the failure frequency per class of material grade, one for the period 1970-2013, the other for the period 2004-2013. The 3rd and 4th graph give a further breakdown of the failure frequency per size of leak.

Grade A material has the highest failure frequency for “material failure” in the period 1970-2013, although in the period 2004-2013, no incidents were caused by material failure on grade A pipelines.

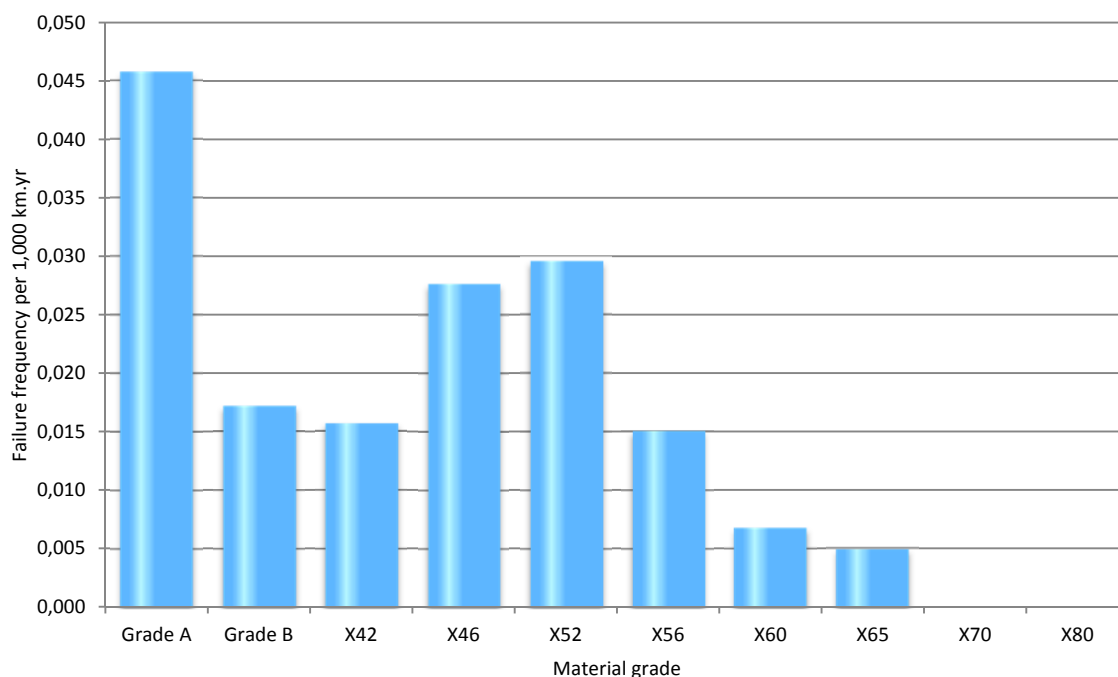


Figure 50: Relation Material failure and material grade (1970-2013)

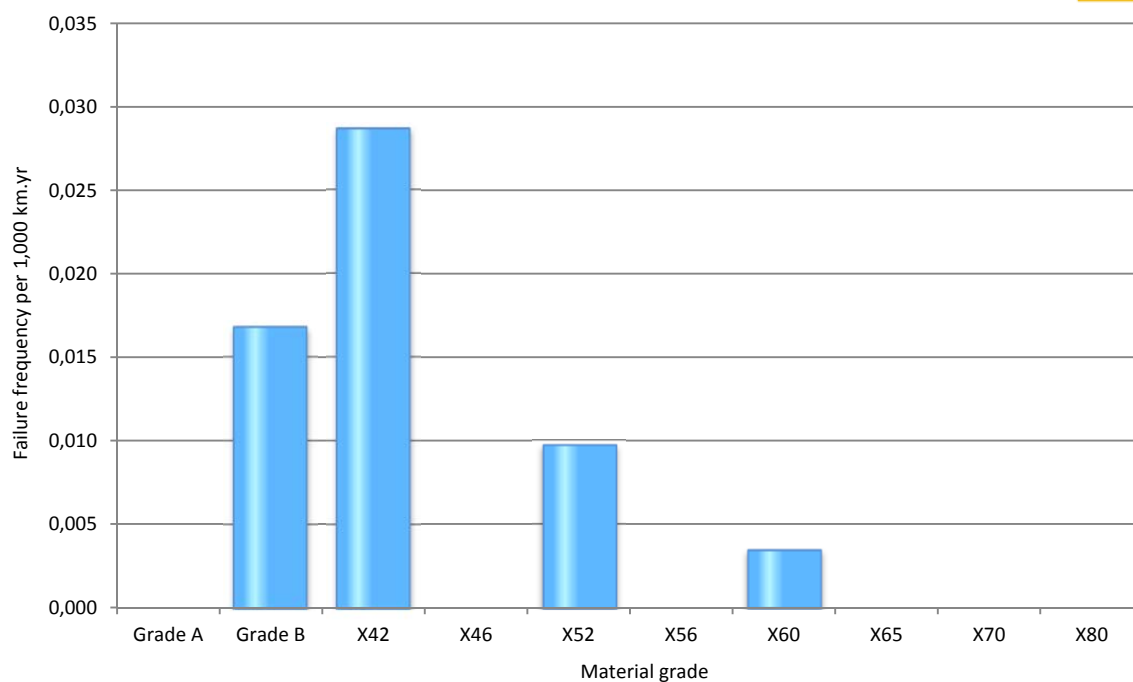


Figure 51: Relation Material failure and material grade (2004-2013)

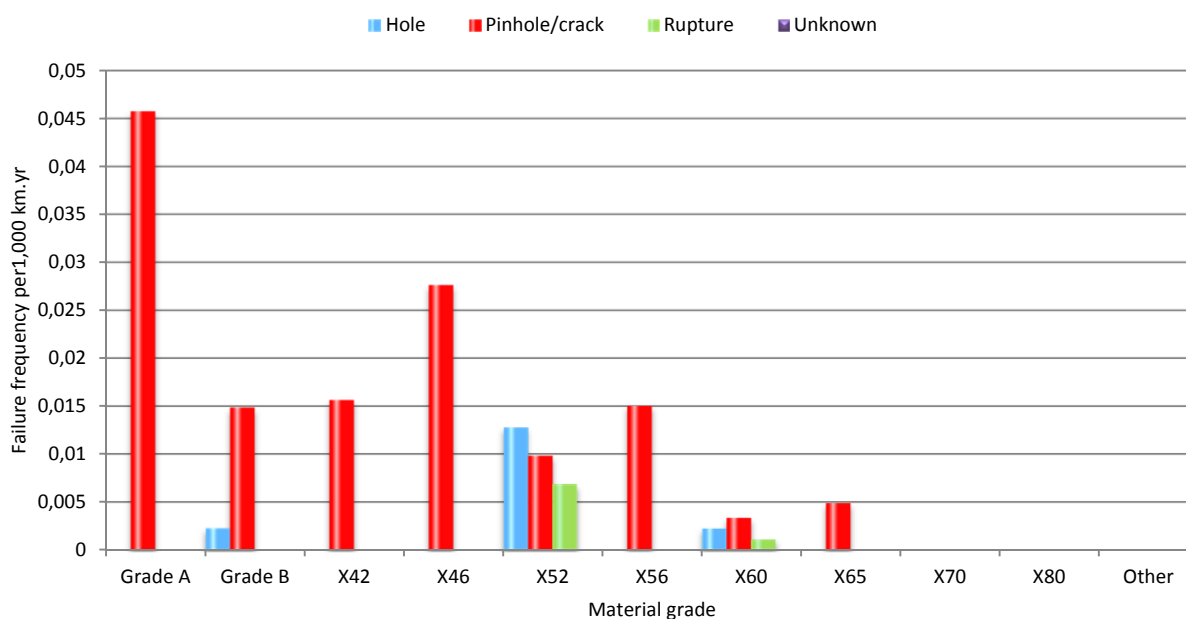


Figure 52: Relation material failure, size of leak and material grade (1970-2013)

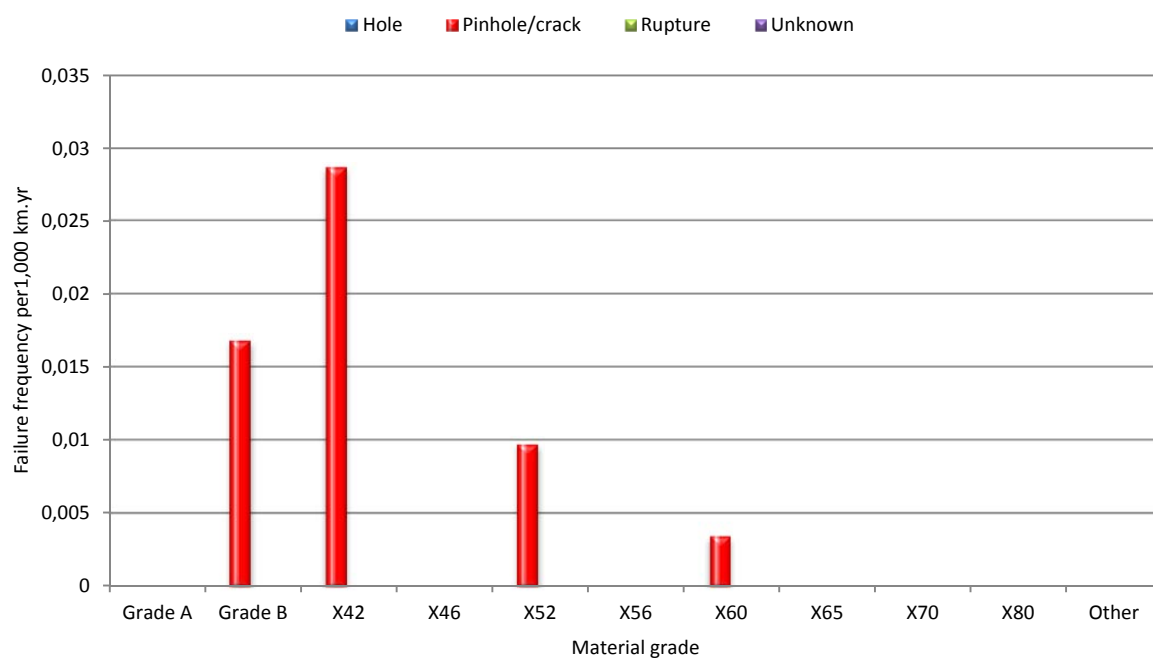


Figure 53: Relation material failure, size of leak and material grade (2004-2013)

3.3.3.4 Relation 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 54 to Figure 57 show the failure frequencies for the incident cause "hot tap made by error" for different pipeline diameter classes and leak sizes. The first two graphs present the failure frequency per pipeline diameter class, one for the period 1970-2013, the other for the period 2004-2013. The 3rd and 4th graph give a further breakdown of the failure frequency per size of leak.

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 .

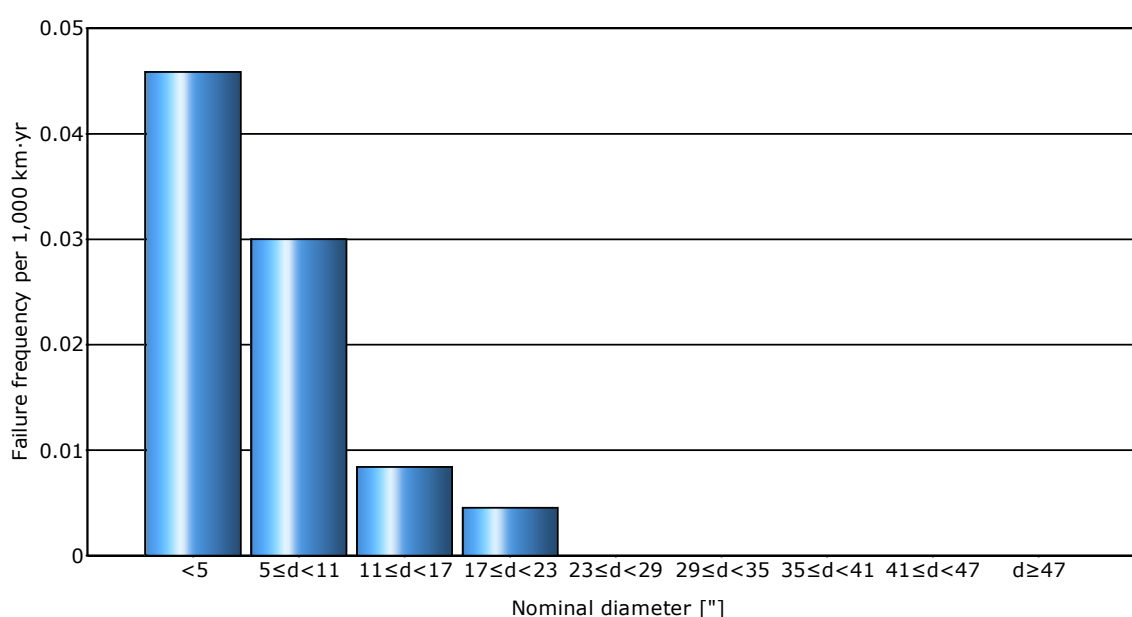


Figure 54: Relation hot tap made by error and diameter (1970-2013)

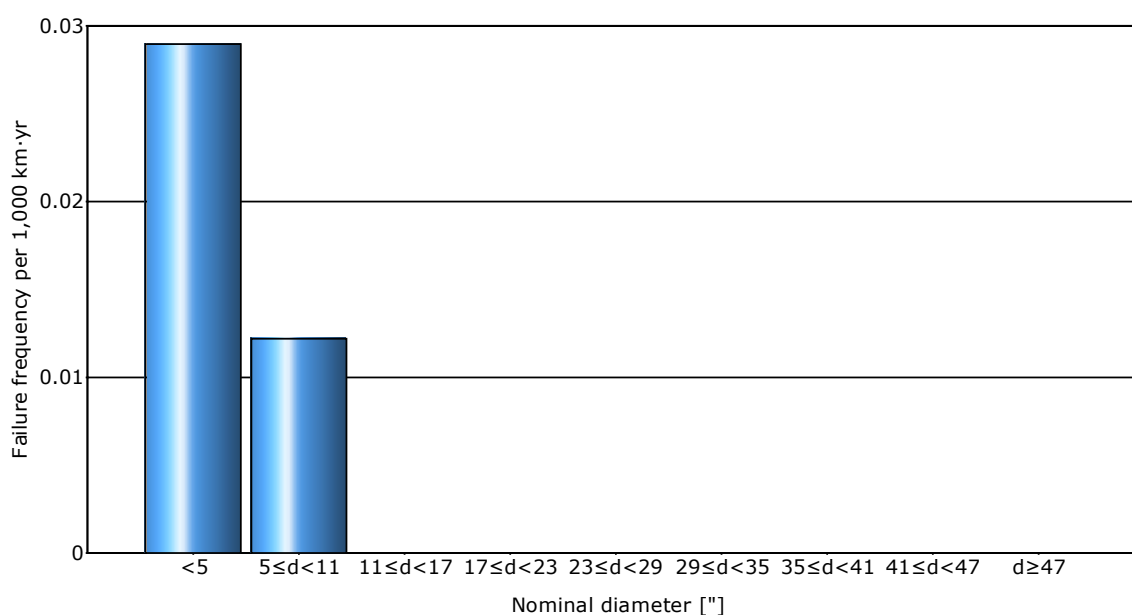


Figure 55: Relation hot tap made by error and diameter (2004-2013)

Figure 54 and Figure 55 illustrate that larger diameter pipelines are less vulnerable to hot tap made by error. Figure 56 and Figure 57 show that this kind of error has led to pinholes and holes, especially with smaller diameter pipelines.

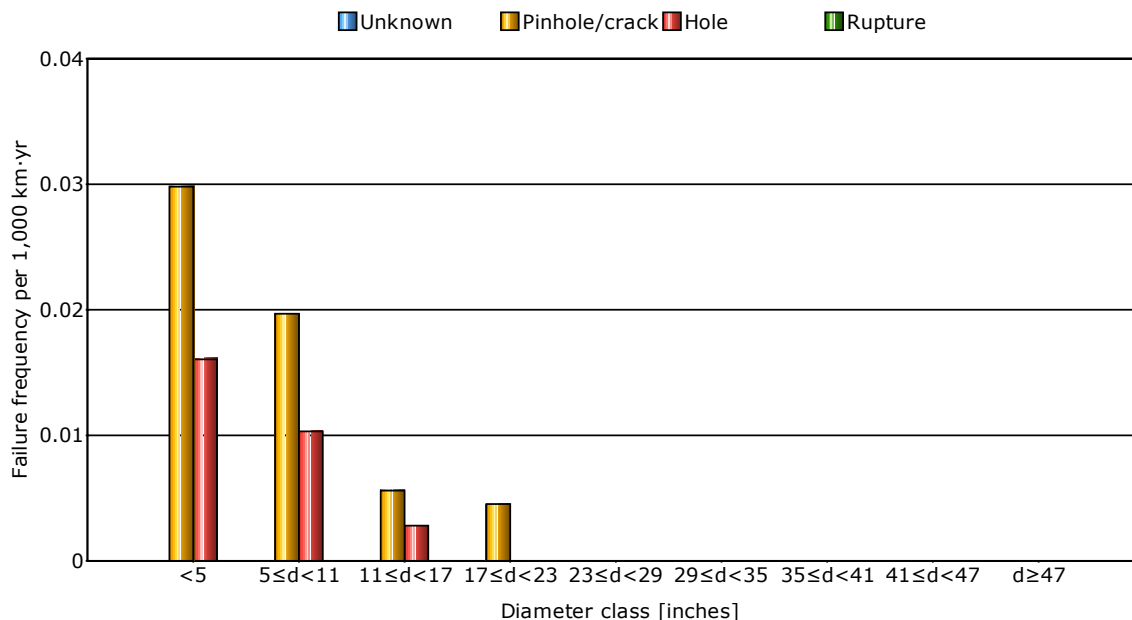


Figure 56: Relation hot tap made by error, size of leak and diameter (1970-2013)

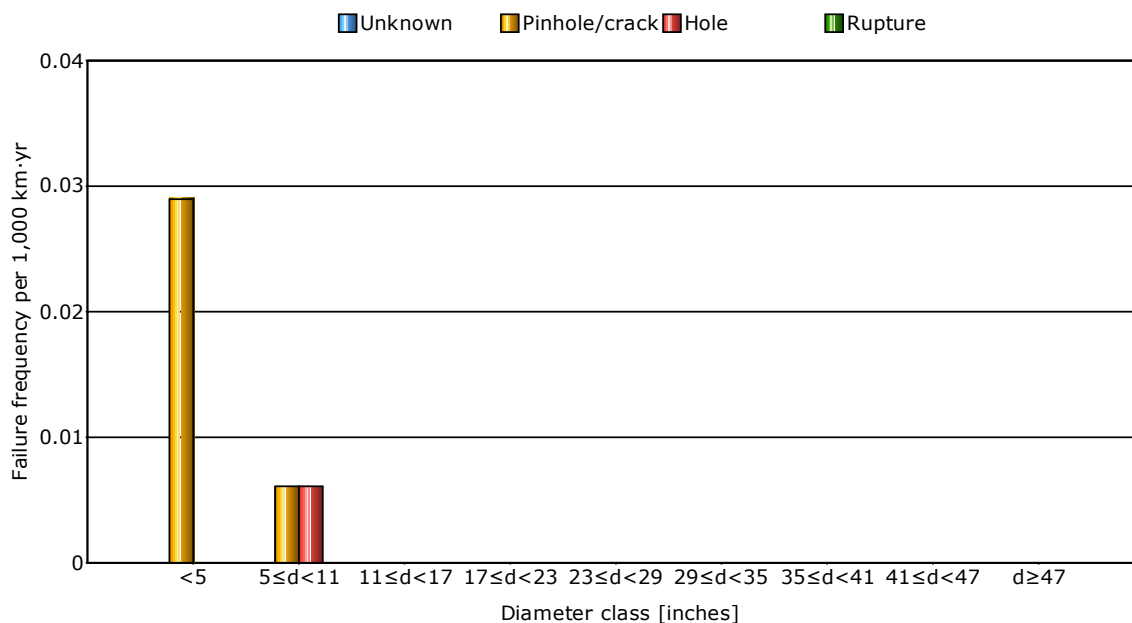


Figure 57: Relation hot tap made by error, size of leak and diameter (2004-2013)

3.3.3.5 Ground movement

Ground movement is responsible for 8% of the total incidents of the database.

Figure 58 to Figure 61 show the failure frequencies for the incident cause “ground movement” for different pipeline diameter classes and leak sizes. The first two graphs present the failure frequency per pipeline diameter class, one for the period 1970-2013, the other for the period 2004-2013. The 3rd and 4th graph give a further breakdown of the failure frequency per size of leak.

From these figures some conclusions can be drawn:

For the period 1970-2013 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.

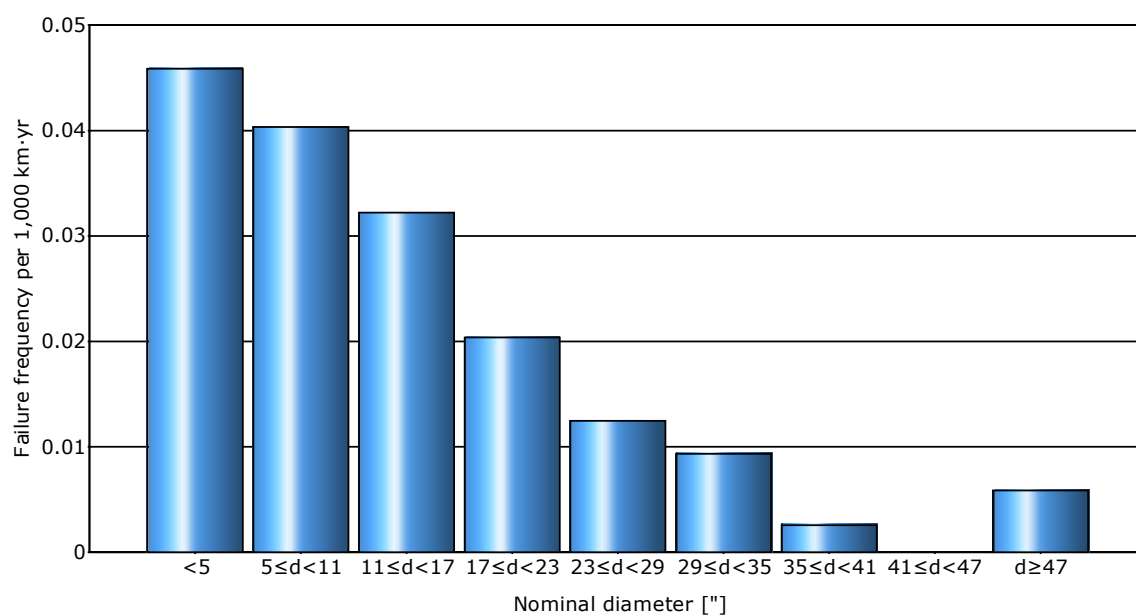


Figure 58: Relation ground movement and diameter (1970-2013)

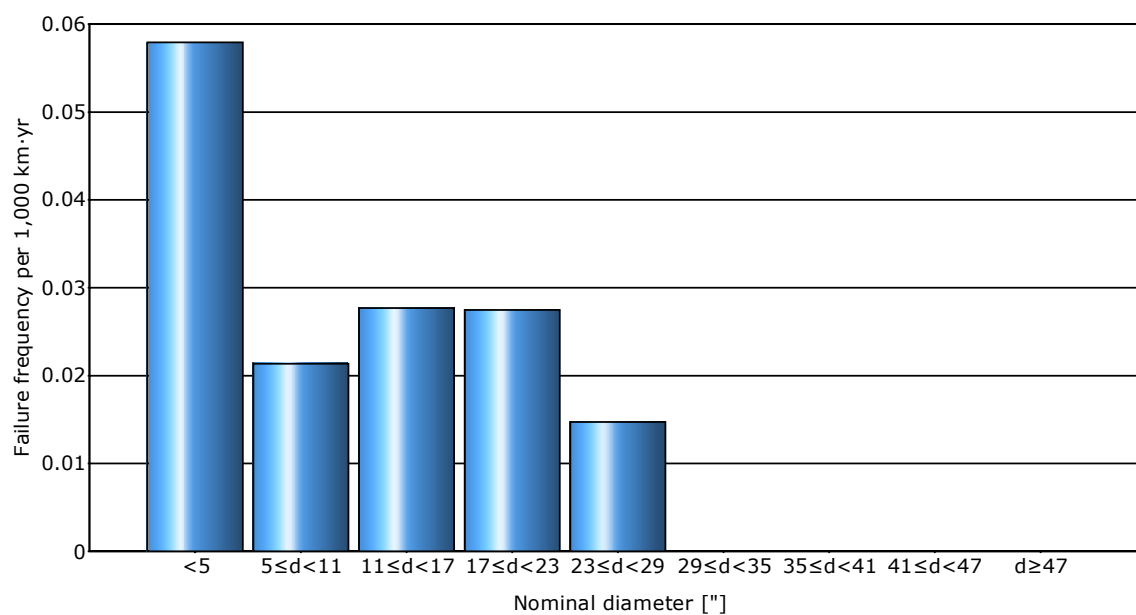


Figure 59: Relation ground movement and diameter (2004-2013)

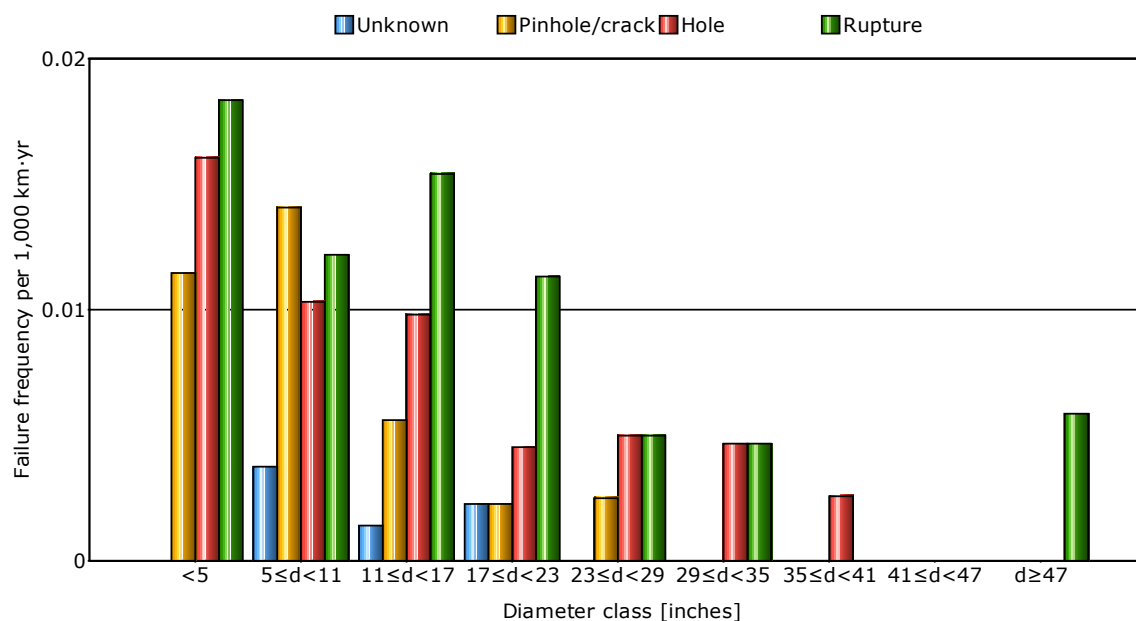


Figure 60: Relation ground movement, size of leak and diameter (1970-2013)

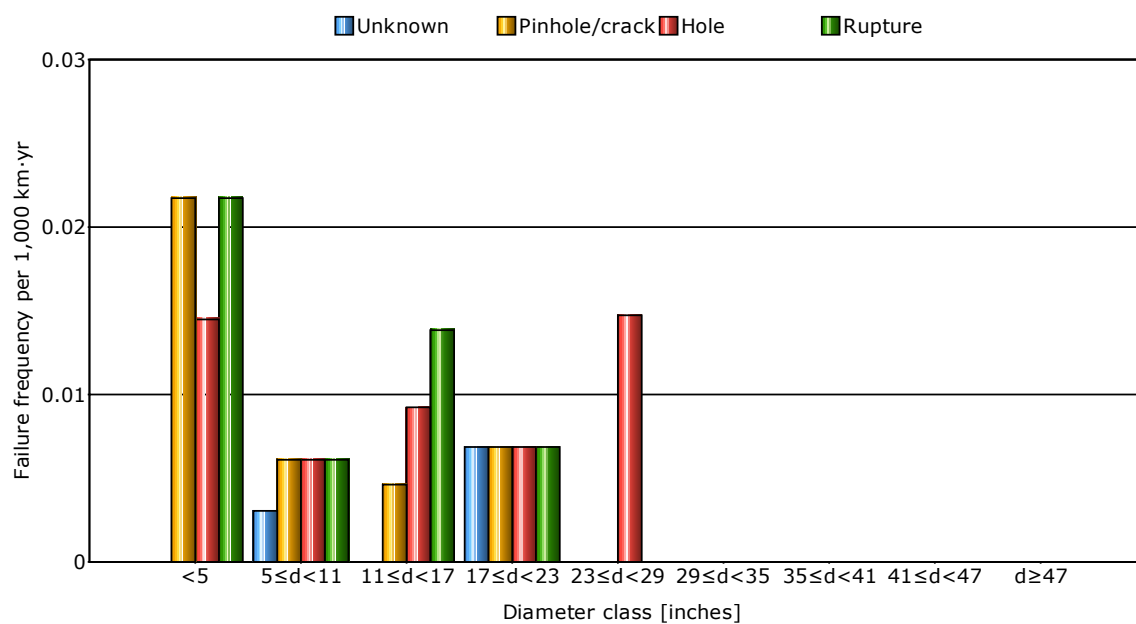


Figure 61: Relation ground movement, size of leak and diameter (2004-2013)

There are many types of “Ground movement” incidents. Figure 62 and Figure 63 give some 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.

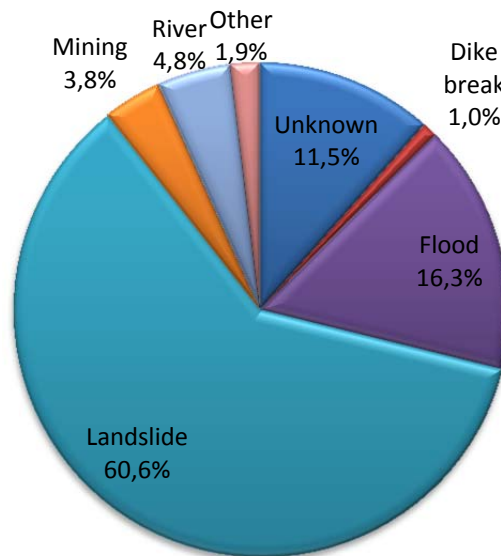


Figure 62: Distribution of the sub-causes of ground movement (1970-2013)

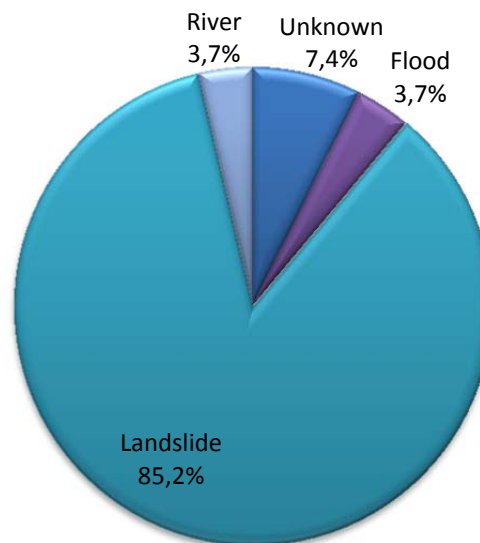


Figure 63: Distribution of the sub-causes of ground movement (2004-2013)

3.3.3.6 Other and unknown

In the category “other and unknown”, incidents caused by “lightning” account for almost 28% of the incidents.

Within the period 1970-2013, 25 incidents due to lightning have been recorded in the EGIG database, which represents a failure frequency due to lightning equal to 0.006 per 1,000 km·yr. EGIG examined the distribution of the consequences of lightning in terms of leak sizes.

Out of 25 incidents, 23 were pinholes/cracks and only 2 resulted in a hole.
No incidents were recorded that were caused by earthquakes.

3.4 Other analyses

3.4.1 Ageing

The influence of the age of the pipelines on their failure frequencies has been studied in the ageing analysis.

In this ageing 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.

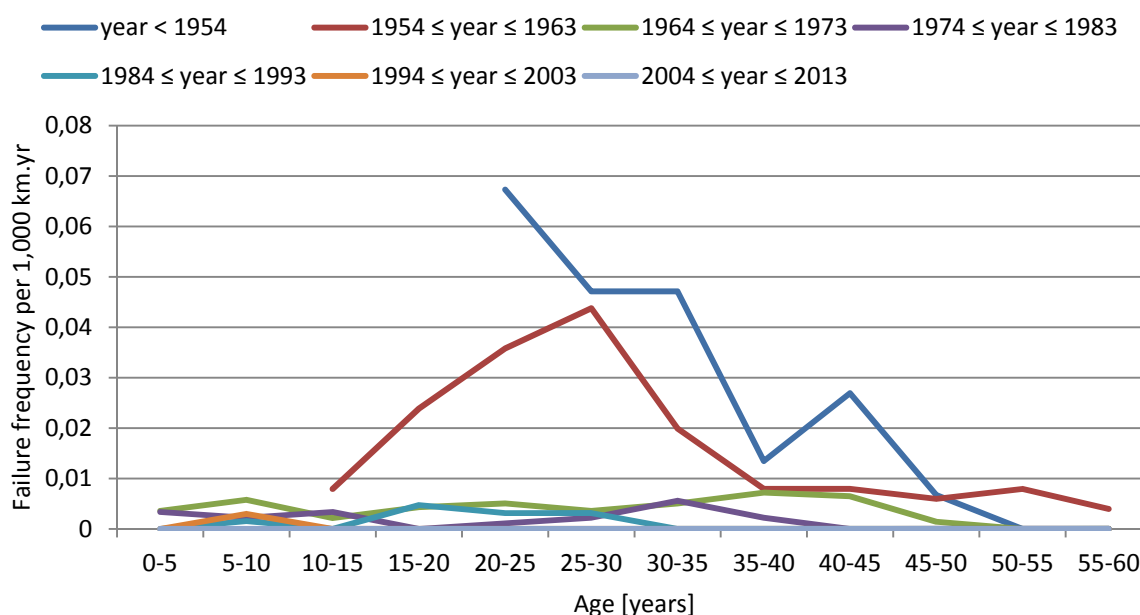


Figure 64: Ageing analysis (corrosion)

Explanation Figure 64.

Taking for instance a pipeline constructed before 1954: the failure frequency 20 to 25 years after construction is 0.067 per 1,000 km·yr, whereas it is 0.013 per 1,000 km·yr after 35-40 years.

The first conclusion of Figure 64 is that early constructed pipelines (before 1964) have indeed a higher failure frequency than recently constructed pipelines. However, a second conclusion is that the failure frequencies of the pipelines constructed before 1964 have slightly decreased in time after an age of 25 to 30 years.

Pipelines constructed, commissioned and operated before 1960s are subject to failure due to corrosion. Pipelines constructed after 1964, have a failure frequency lower than 0,01 per 1,000 km·yr for corrosion.

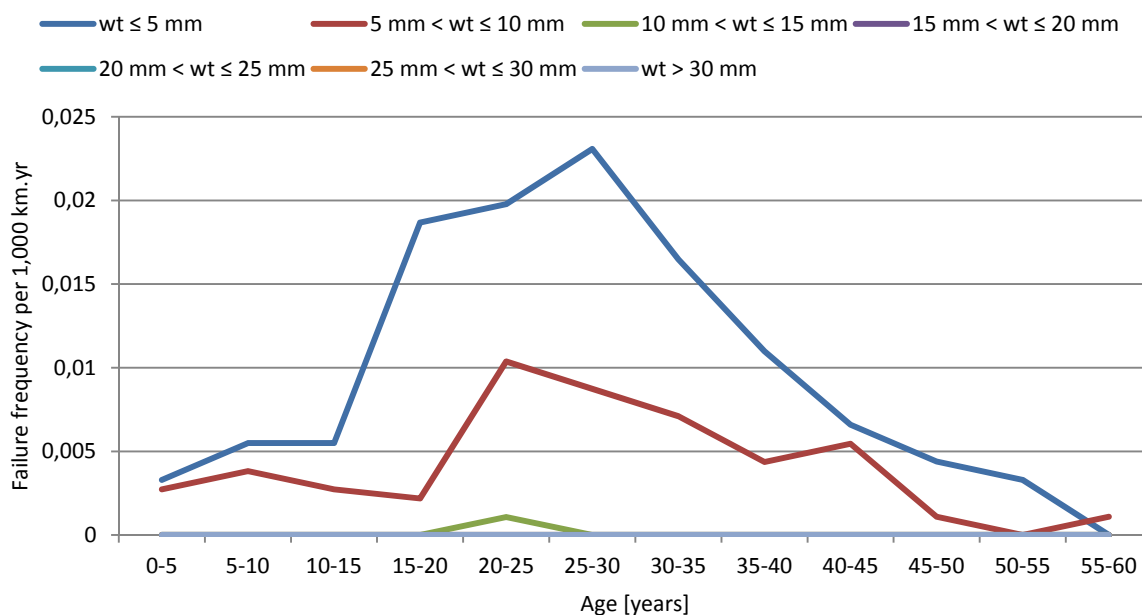


Figure 65: Ageing analysis corrosion vs wall thickness

From Figure 65, it can be seen that no corrosion incidents were reported for pipelines with wall thicknesses larger than 15 mm. Pipelines with smaller wall thicknesses are affected most by ageing. Higher wall thicknesses protect against failure due to corrosion, so corrosion incidents will occur later in time and with a lower failure frequency.

3.4.2 Ignition of releases

Fortunately, not every gas release ignites, which limits the consequences of the incidents. In the period 1970-2013, only 5.0% of the gas releases recorded in the EGIG database ignited.

Pipeline ruptures with ignition can cause severe societal damage. This is especially the case for pipelines with larger diameters. Figure 66 shows that gas releases from large diameter pipelines at high pressure have ignited more frequently than smaller diameter pipelines 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 "Ignition Probability for High Pressure Gas" [Ref 4] an analysis is made of ignition probabilities. The paper shows that even ruptures of large diameters and high pressure do not always ignite.

Information on ignited releases is presented in Table 6 as a function of size of leak.

Size of leak	% of releases with ignition
Pinhole-crack	4.4
Hole	2.3
Rupture (all diameters)	13.9
Rupture ≤ 16 inches	10.3
Rupture > 16 inches	32

Table 6: Ignition of releases per leak type

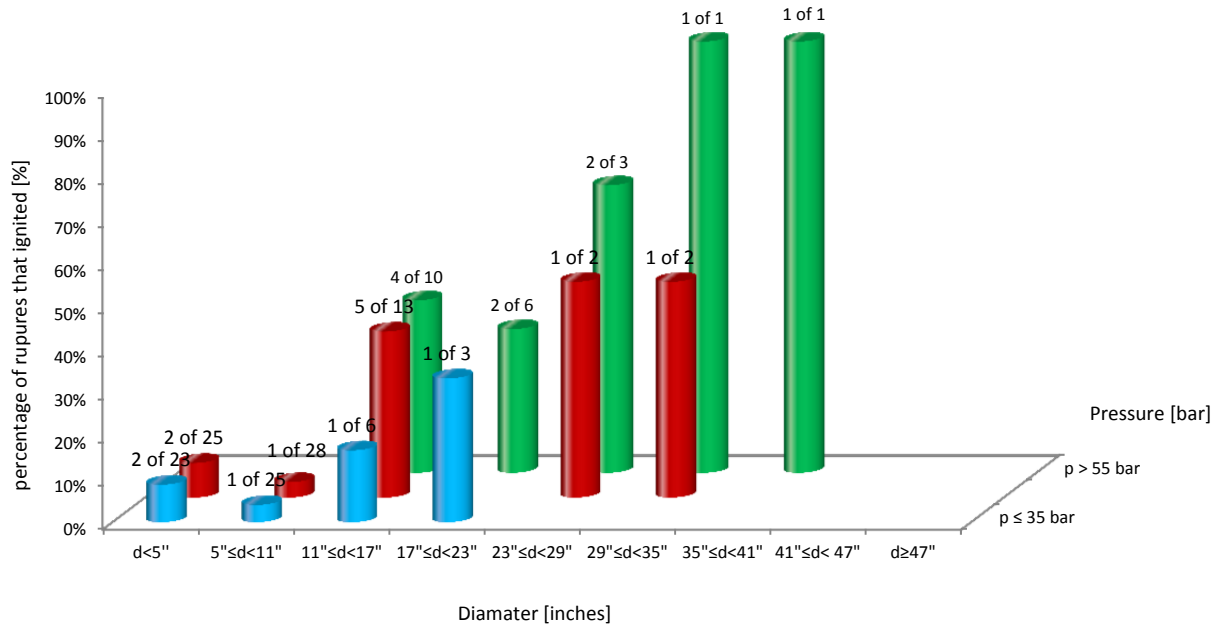


Figure 66: Percentages of ruptures that ignited subdivided in diameter and pressure (1970-2013)

3.4.3 Injuries and fatalities

EGIG gives information about failure frequencies and causes of incidents. Some of the registered incidents unfortunately caused injuries and even fatalities.

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 database of EGIG only contains qualitative information about the consequences of incidents. The EGIG database contains a total of 1309 incidents. Figure 67 shows that the highest fatality and injury rate can be found among the people who are directly involved in causing the incident. In 8 cases (0.61%) these incidents caused fatalities among the people causing the incident. Two cases of the incidents involved fatalities of the public. In Figure 68 it can be seen that the fatalities mainly occurred with ruptures.

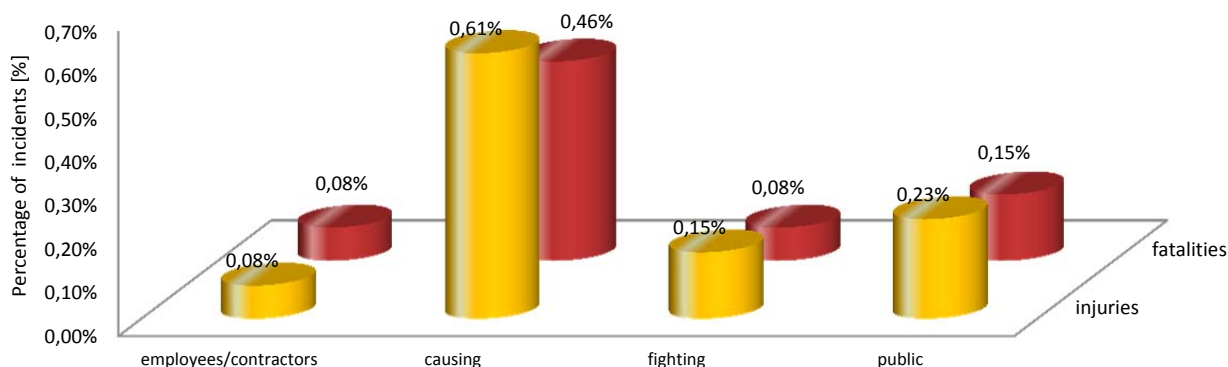


Figure 67: Percentage of accidents of groups involved in pipeline incidents (1970-2013)

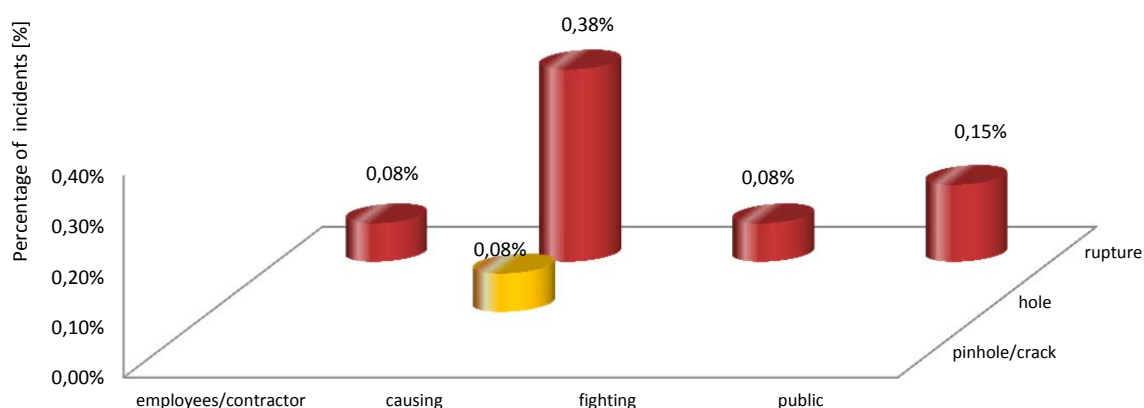


Figure 68: Percentage fatalities of accidents of groups as a function of leak size (1970-2013)

Together with the low failure frequencies of pipelines, it can be concluded that gas pipelines are a safe means of transporting energy.

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 7 shows the distribution per type. The public is the most common detector, with approximately 36% of the incidents. In the period 1970-2013, 16% of the incidents were detected by the patrols and 15% by contractors.

Detection	Incident distribution 1970 – 2013 [%]	Incident distribution 2004 – 2013 [%]
Public	36.1	24.9
Patrol + Contractors + Staff	39.6	38.8
Unknown	7.3	1.4
Landowner	5.0	14.4
Distribution company	4.8	4.3
Other	5.5	11.5
In-line inspection	1.8	4.8

Table 7: Detection of incidents

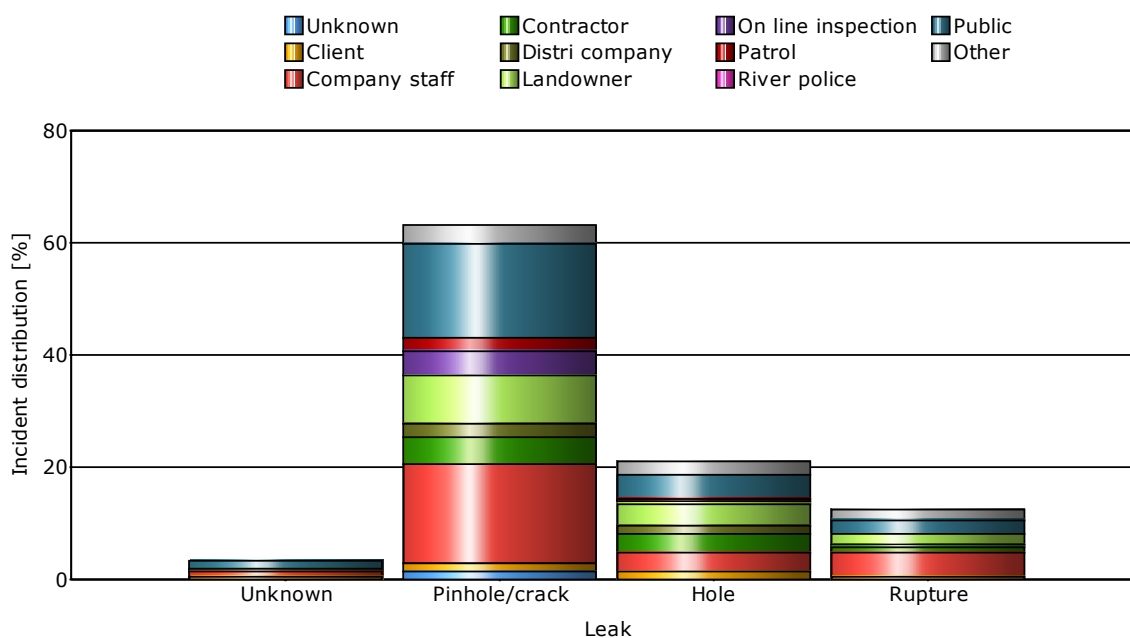


Figure 69: Detection of incidents per leak size (2004-2013)

Figure 69 shows that most pinhole/cracks are detected by company staff and public. Holes and ruptures are mainly detected by the public, company staff and landowners.

4 CONCLUSIONS

- 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 143,000 km of pipelines every year. The total exposure, which expresses the length of a pipeline and its period of operation, is 3.98 million km·yr.
- In the EGIG database 1309 pipeline incidents are recorded in the period from 1970-2013.
- The history of incidents collected in the database gives reliable failure frequencies. The overall incident frequency is equal to 0.33 incidents per year per 1,000 km over the period 1970-2013.
- The 5-year moving average failure frequency in 2013, which represents the average incident frequency over the past 5 years, equals 0.16 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 which emphasises their importance to pipeline operators and authorities.
- Corrosion as a primary cause has increased over the last five years and is now of the same magnitude as external interference, although consequences are much less severe.
- Over the last ten years, external interference, corrosion, construction defects and ground movement, represent 35%, 24%, 16% and 13% respectively of the pipeline incidents reported.

5 REFERENCES

- 1: 7th Report of the European Gas Pipeline Incident Data Group, 1970-2007, December 2008.**
- 2: 8th Report of the European Gas Pipeline Incident Data Group, 1970-2010, December 2011**
- 3: API Spec 5L: Specification for Line Pipe**
- 4: Michael R. Acton and Philip J. Baldwin, Ignition Probability for High Pressure Gas Transmission Pipelines, 2008 7th International Pipeline Conference**

APPENDIX 1: Statistics

Primary failure frequencies over different time intervals

Period	Interval [years]	Number of incidents	Total system exposure $\cdot 10^6$ 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	7 th report 38 years	1173	3.15	0.372	0.351	0.394
1970 - 2010	8 th report 41 years	1249	3.55	0.351	0.333	0.372
1970 -2013	9 th report 44 years	1309	3.98	0.329	0.311	0.347
1974 -2013	40 years	1179	3.84	0.307	0.290	0.325
1984 -2013	30 years	805	3.24	0.249	0.232	0.267
1994 -2013	20 years	426	2.40	0.177	0.161	0.195
2004 -2013	10 years	209	1.33	0.157	0.137	0.180
2009 -2013	5 years	110	0.70	0.158	0.130	0.190

Table 8: Primary failure frequencies over different time intervals and their 95 % confidence 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
Pinhole/crack	0.105	0.082	0.132
Hole	0.030	0.019	0.046
Rupture	0.016	0.008	0.028

Table 9: Primary failure frequencies per leak size (period 2009–2013) and their 95 % confidence intervals

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	0.156	0.144	0.169
Corrosion	0.055	0.048	0.062
Construction defect / Material failure	0.055	0.048	0.062
Hot tap made by error	0.015	0.012	0.019
Ground movement	0.026	0.021	0.032

Table 10: Primary failure frequencies per cause (1970-2013) and their 95 % confidence intervals

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	0.055	0.043	0.069
Corrosion	0.038	0.028	0.050
Construction defect / Material failure	0.025	0.017	0.035
Hot tap made by error	0.006	0.003	0.012
Ground movement	0.020	0.013	0.030

Table 11: Primary failure frequencies per cause (2004-2013) and their 95 % confidence intervals

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	0.044	0.030	0.063
Corrosion	0.042	0.028	0.060
Construction defect / Material failure	0.026	0.015	0.041
Hot tap made by error	0.009	0.003	0.019
Ground movement	0.024	0.014	0.039

Table 12: Primary failure frequencies per cause (2009-2013) and their 95 % confidence intervals

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

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

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

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.

REFERENCE

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