



# **GAS PIPELINE INCIDENTS**

**8<sup>th</sup> Report of the European Gas Pipeline Incident Data Group**

## **Comprising:**

Bord Gais (Ireland)  
DGC (Denmark)  
ENAGAS, S.A. (Spain)  
Fluxys (Belgium)  
Gasum (Finland)  
GRT Gaz (France)  
National Grid (UK)  
N.V. Nederlandse Gasunie (The Netherlands)  
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European Gas Pipeline Incident Data Group (EGIG):**

Bord Gais (Ireland)  
DGC (Denmark)  
ENAGAS, S.A. (Spain)  
Fluxys (Belgium)  
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<sup>1</sup> 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 (**E**uropean **G**as pipeline **I**ncident data **G**roup). Presently, EGIG is a cooperation of fifteen 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 rates and causes of failures in the gas transmission pipelines systems.

This report provides a broad basis for statistical use.

## Conclusions and facts from the 8<sup>th</sup> EGIG report

- EGIG has maintained and expanded the European Gas pipeline incident database. Transmission companies of fifteen European countries now collect incident data on more than 135,000 km of pipelines every year. The total exposure, which expresses the length of a pipeline and its period of operation, is 3.55 million km·yr.
- The statistics of incidents collected in the database give reliable failure frequencies. The overall incident frequency is equal to 0.35 incidents per year per 1,000 km over the period 1970 to 2010.
- The 5 year moving average failure frequency in 2010, 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 has reduced consistently over the years, although it has tended to stabilise.
- The high contribution of external interference emphasises its importance to pipeline operators and authorities.
- External interference incidents are characterised by potentially severe consequences.
- External interference incidents have reduced over the years so that they are now of a similar order to that of corrosion and construction/material defects.

## **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 fifteen major 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:

- Bord Gais (Ireland)
- DGC (Denmark)
- ENAGAS, S.A. (Spain)
- Fluxys (Belgium)
- Gasum (Finland)
- GRT Gaz (France)
- National Grid (UK)<sup>1</sup>
- NET4GAS (Czech Republic)
- N.V. Nederlandse Gasunie (The Netherlands)
- OMV Gas GmbH (Austria)
- Open Grid Europe (Germany)
- Ren Gasodutos S.A. (Portugal)
- Snam Rete Gas (Italy)
- Swedegas A.B. (Sweden)
- SWISSGAS (Switzerland)

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 regional differences such as population density, geological conditions are not taken into account. The results of the database present an average of all participating companies.

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 will be presented during the 25<sup>th</sup> edition of the International Gas Union (IGU) World Gas Conference in 2012 in Malaysia.

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<sup>1</sup> Representing National Grid, Scotia Gas Networks, Wales and the West Utilities and Northern Gas Networks.

This report introduces 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.

### **International developments for pipeline databases**

The International Gas Union (IGU) performed an investigation in which world wide databases were compared. Most of the databases are collecting incidents but no system information like the total length of the pipeline grid or a subdivision of this.

In order to develop a world wide database from the individual databases a lot of work has to be done in collecting system information. For the EGIG only the changes from year to year have to be undertaken.



## **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 the EGIG database is to collect and present data on loss of gas incidents to present the safety performance of the European gas transmission pipelines and to provide a broad basis for statistical use.

### **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.

General information about pipeline system is given per year on pipeline length categorised according to:

- Diameter
- Pressure
- Year of construction
- Type of coating
- Cover
- Grade of material
- Wall thickness
- In Line Inspection

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 diameter of the hole is smaller than or equal to 2 cm
  - Hole: the diameter of the hole is larger than 2 cm and smaller than or equal to the diameter of the pipe
  - Rupture: the 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 (external, internal or unknown)
  - The corrosion type (galvanic, pitting, stress corrosion cracking "SCC" or unknown)
  - Whether or not a pipeline was in line inspected
- 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.

Most of the information mentioned here has been used for the statistics given in this 8<sup>th</sup> EGIG report.

## **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 have decided to publish statistics of pipeline data over different time intervals. In this report the statistics of the whole database (approximately 40 years), but also the most important statistics of the last 30-, 20-, 10-years and the 5 years moving average are reported. It must be noted that given the theory of statistics the mean value over five years has a lower reliability than 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.

The EGIG database offers an overview of the failure frequencies of the European gas transmission pipelines system. It gives information on the distribution of incidents per pipeline design 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**

The objective of data or statistical analysis is 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 ignition probability.

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 class or per depth of cover class.

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

In order to illustrate recent trends a 5-year moving average has been introduced. The 5-year moving average means that the calculations have been performed over the 5 previous years in question.

Two statistical terms are also used in this report, confidence interval and ageing analysis:

- 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 used for the calculated failure frequencies.
- 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.

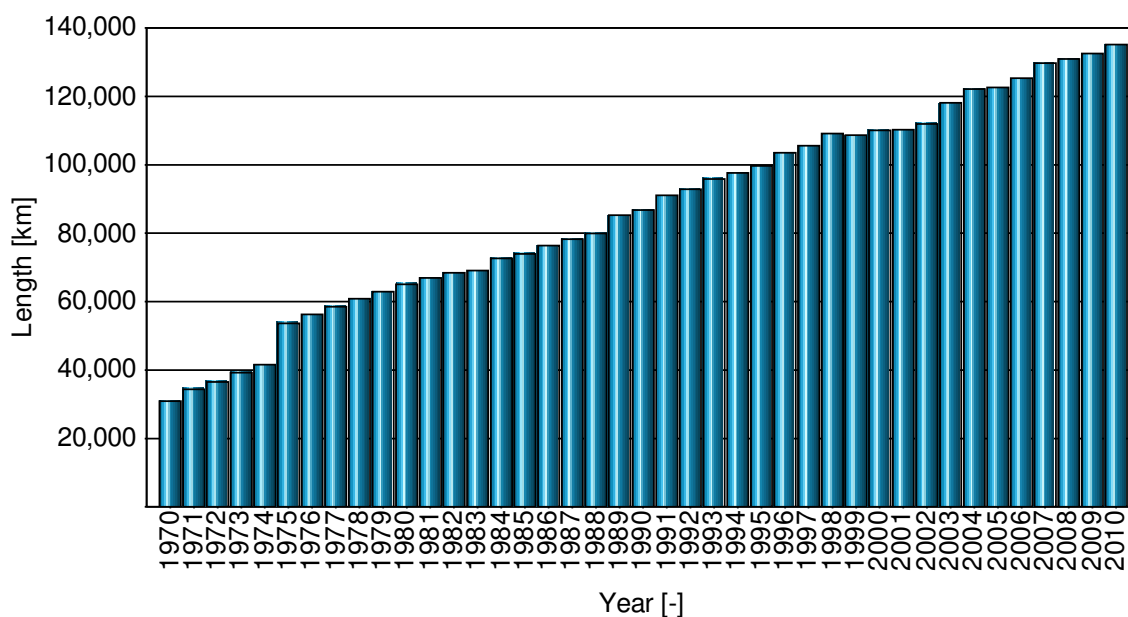
#### **3.2 Trends of the European gas transmission system**

This paragraph gives information on the trends of 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

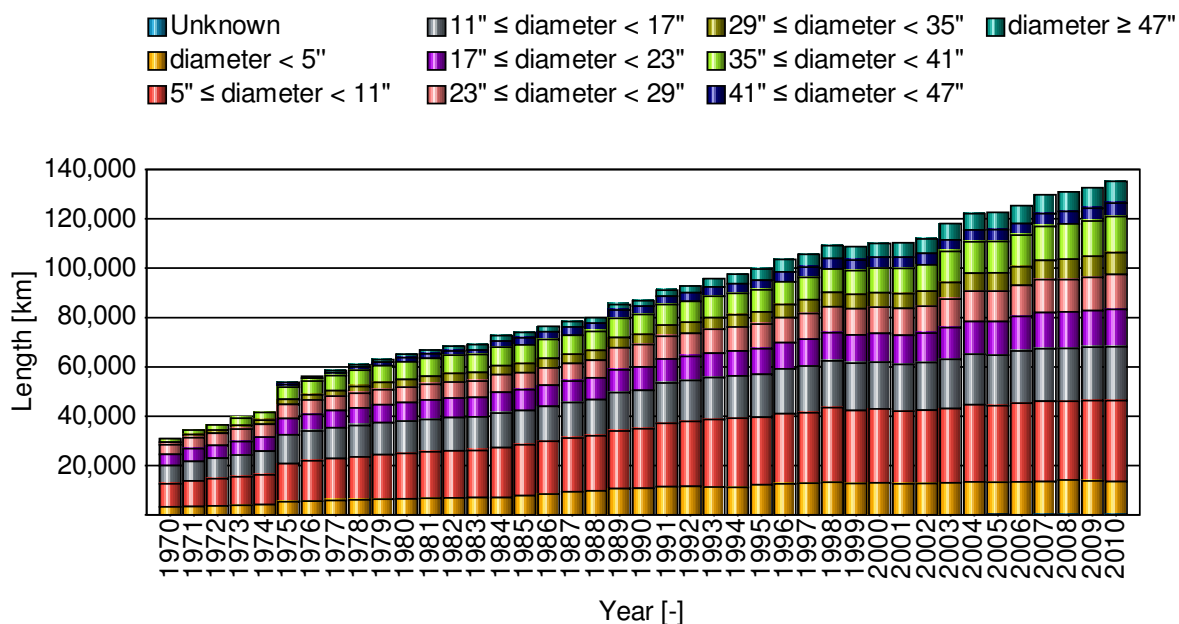
The total length of the European gas transmission pipelines system in EGIG is constantly increasing. In 2007 the annual length was equal to 129,719 km against 135,211 km in 2010. Although no new members were introduced in the last 3 years, it can be seen that there is a steady growth of the system length.

The evolution of the total length of the system is shown in and is also given per category (diameter, pressure, etc.) in figures 2 to 8.



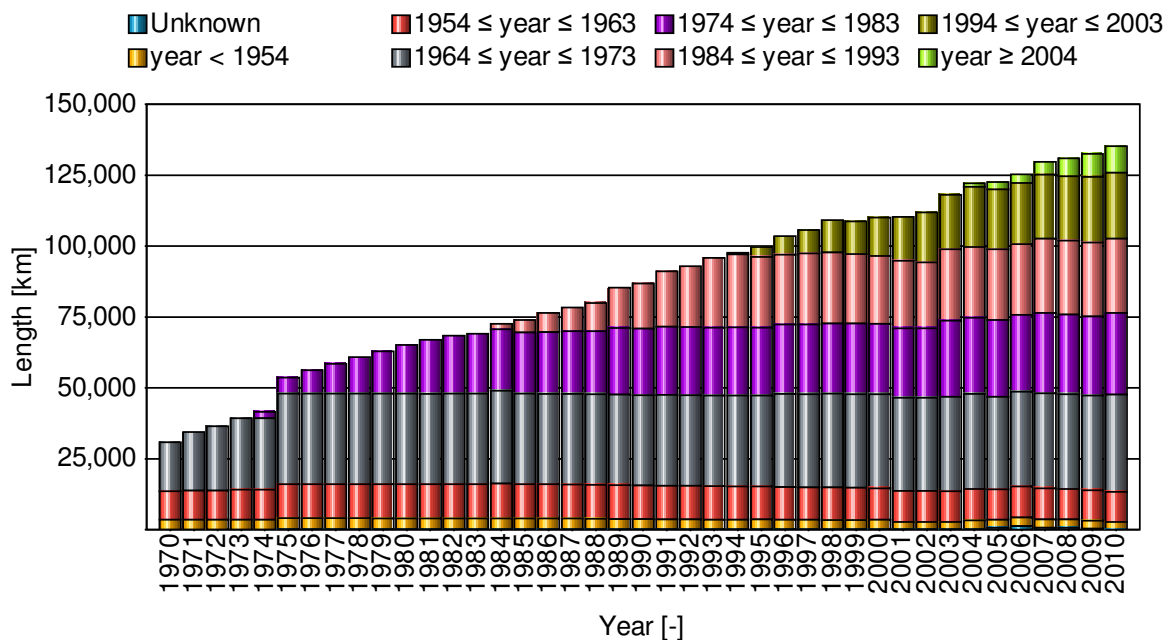
**Figure 1: Total length of the European gas transmission system in EGIG**

Figure 1 shows a linear increase in the length of the European gas transmission system in EGIG, which has significant step changes in the years 1975, 1991, 1998, 2003 and 2007. These changes correspond to new members joining the EGIG. In fact the EGIG is now covering about 50% of all gas pipelines in Europe.



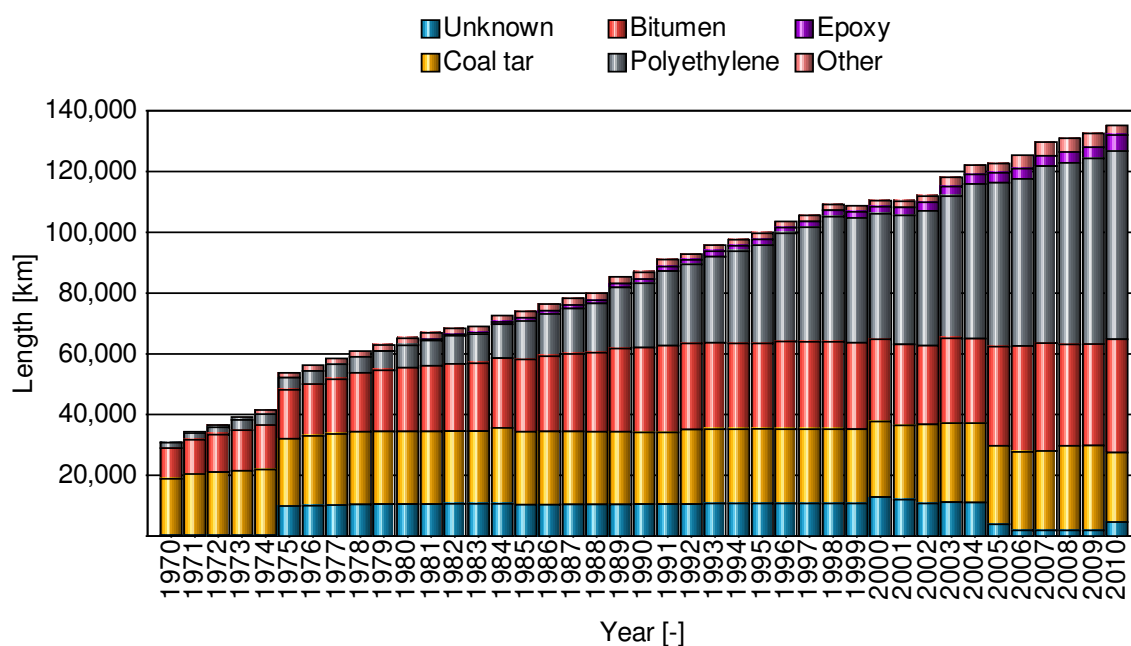
**Figure 2: Total length per diameter (d) class**

Figure 2 demonstrates that the  $5'' \leq d < 11''$  and the  $11'' \leq d < 17''$  classes are still the most commonly used.



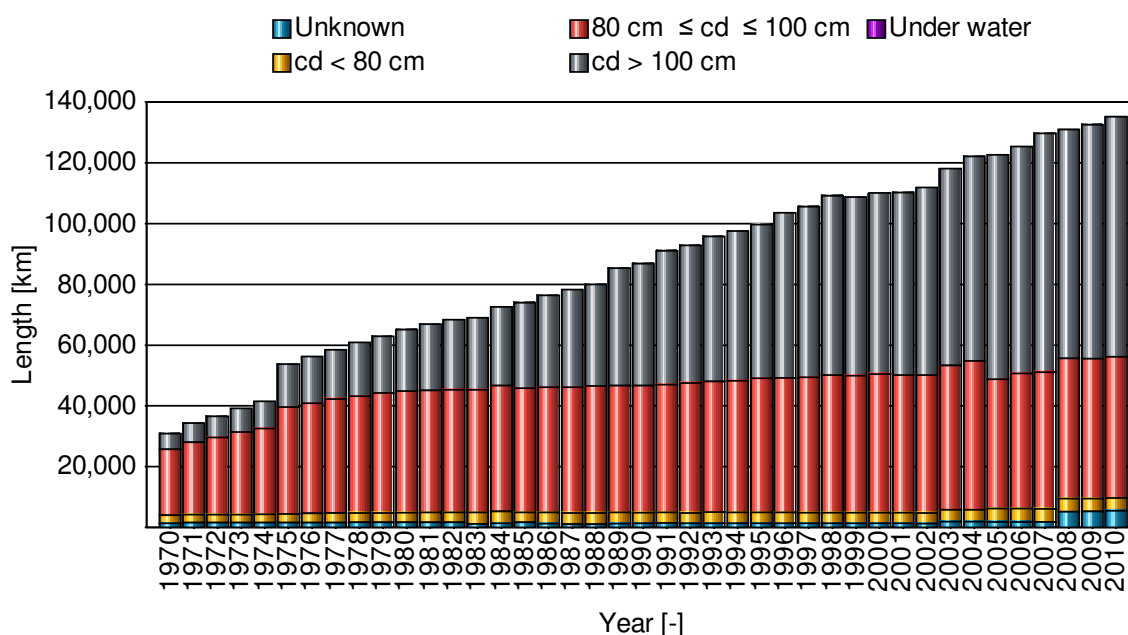
**Figure 3: Total length per year of construction class**

Figure 3 shows that more pipelines were built in the period 1964 -1973 than any other period. No significant drop can be observed, which means that most of these pipelines are still in operation.



**Figure 4: Total length per type of coating**

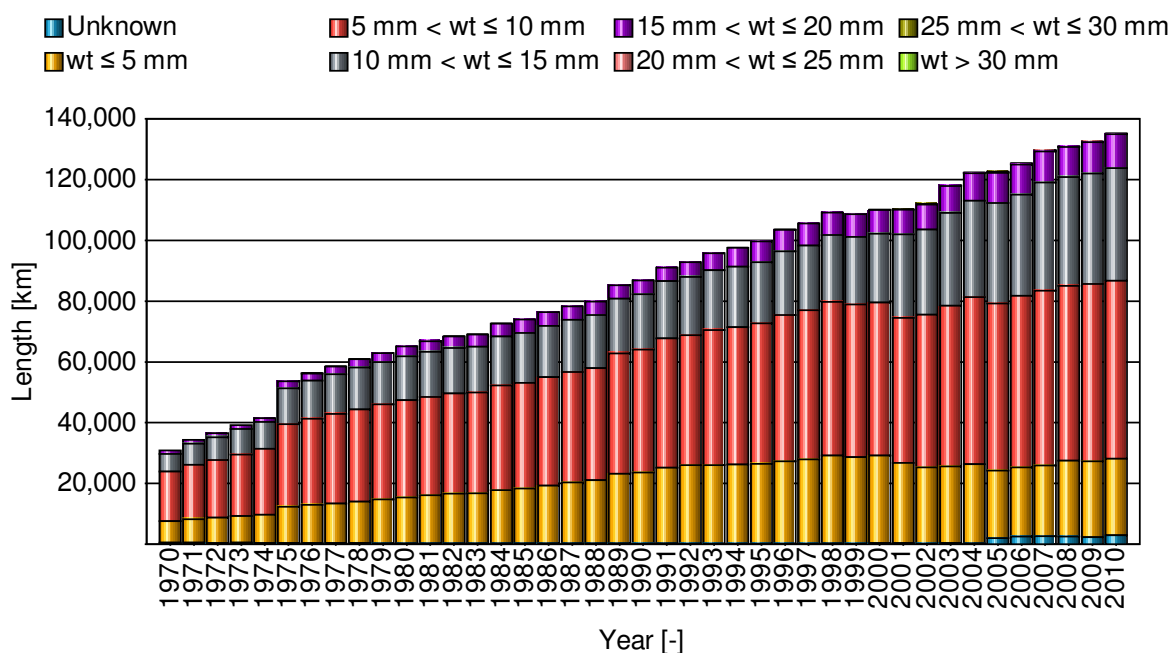
Figure 4 shows that coal tar, bitumen and polyethylene are nowadays the most commonly used coatings with a clear predominance of the last one. From 2004 a drop of the pipeline system with an unknown coating type can be observed.



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

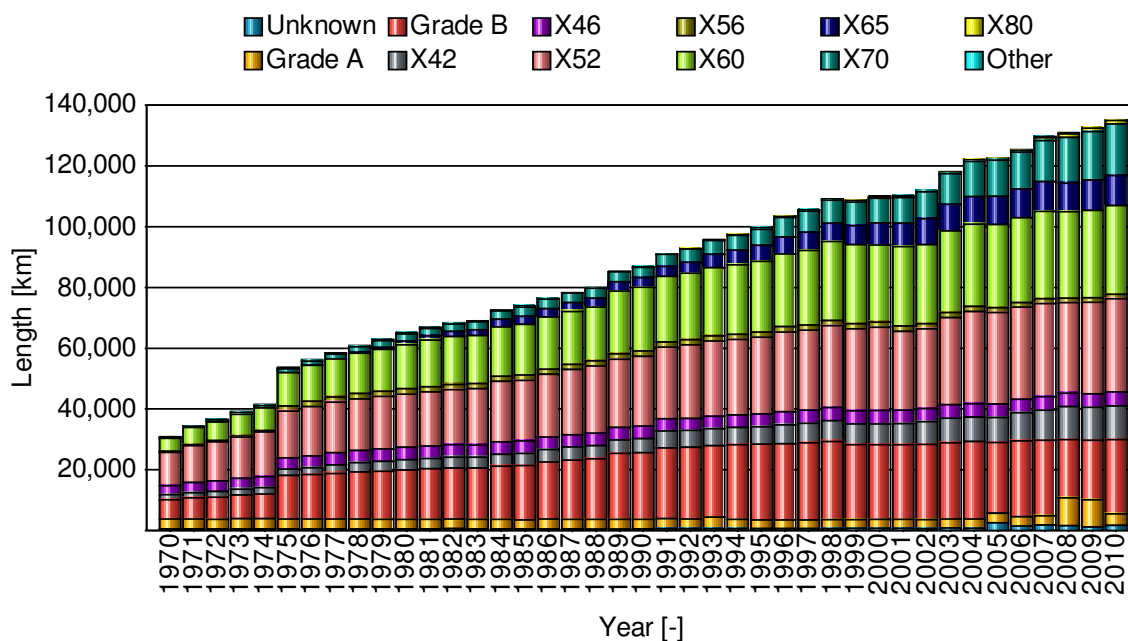
Figure 5 shows that most of the pipelines with a depth of cover less than 80 cm are older pipelines. The trend is obvious that most companies and Design Codes recognise depth of cover as one of the

most important lines of defence against external interference. This can be seen from increase of the pipelines length with a depth of cover larger than 1 meter.



**Figure 6: Total length per wall thickness (wt)**

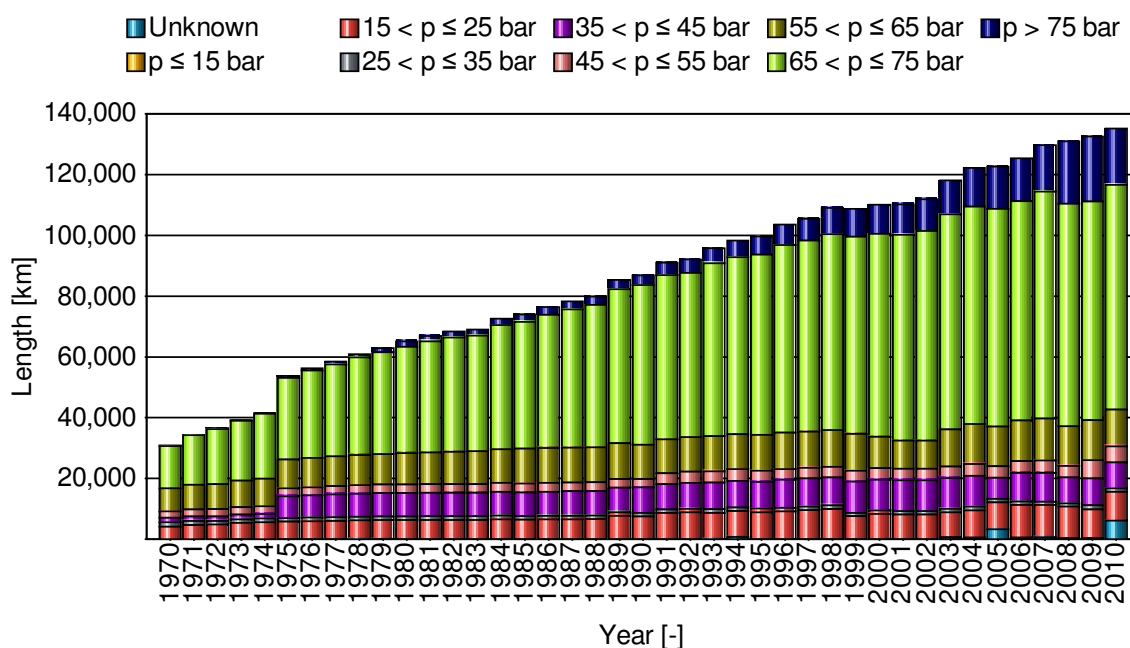
Figure 6 shows that the most commonly used wall thicknesses are 5 to 10 mm. The figure also shows an almost linear increase with a proportional distribution of the wall thickness classes except for the ≤ 5 mm class, which has remained constant since 2001.



**Figure 7: Total length per grade of material**



Figure 7 demonstrates that three grades of material are predominant, namely: Grade B, X52 and X60. Together they represent approximately 62% of the total.

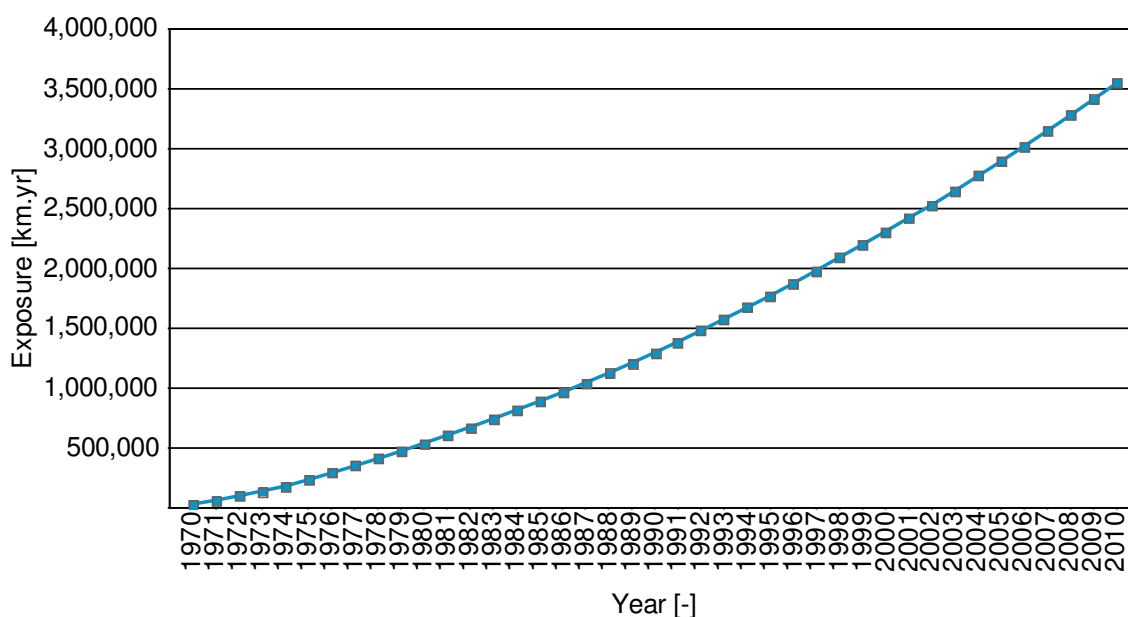


**Figure 8: Total length per Maximum Operating Pressure (p) class**

Figure 8 shows a predominance of the high Maximum Operating Pressure pipelines. The trend is clearly to operate the pipelines at 65 bar and above.

### 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]. For the period 1970-2010, the total system exposure was equal to 3.55 million km·yr.



**Figure 9: Evolution of the exposure**

### 3.3 Failure frequencies analyses

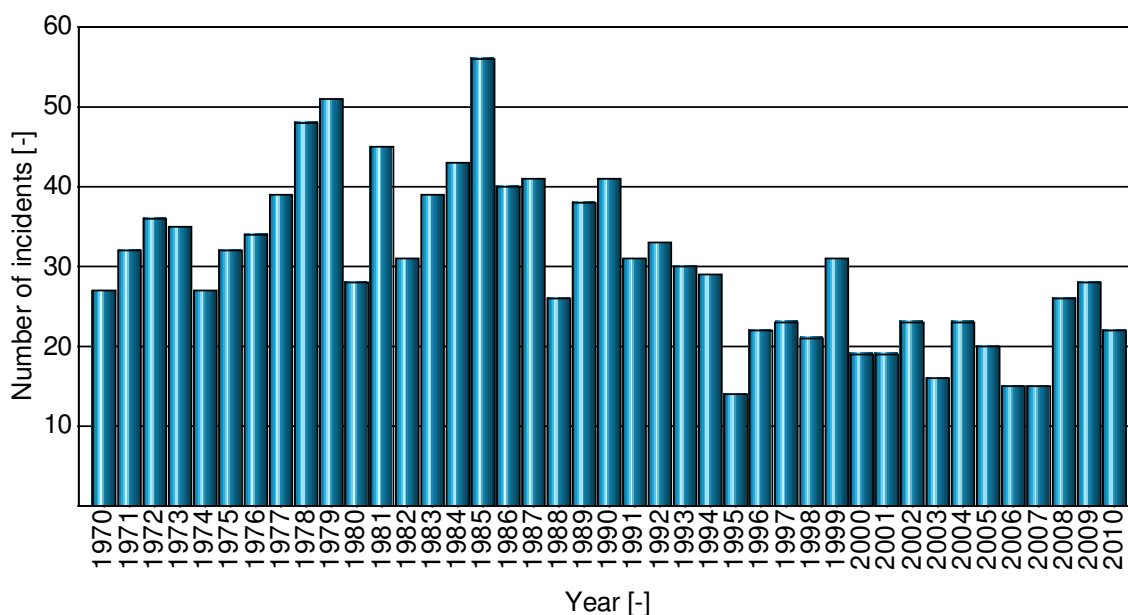
This paragraph deals with the calculation of safety indicators, namely the primary and secondary failure frequencies. These calculations refer to three notions: the total system exposure, the partial system exposure and the number of incidents.

#### 3.3.1 Number of incidents

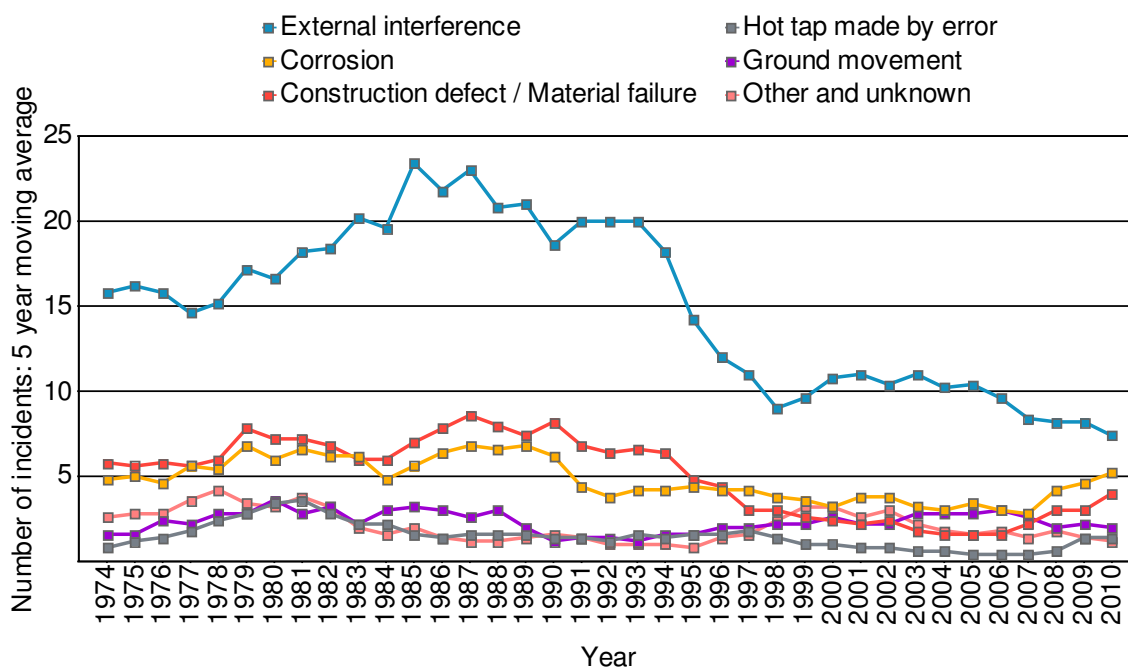
In the seventh EGIG report, which covers the period 1970-2007, a total of 1,173 incidents were recorded.

In the last three years 76 incidents were reported by the EGIG members, which bring the total number of incidents to 1,249 for the period 1970-2010. Figure 10 shows the number of incidents per year and Figure 11 the 5 year moving average of the incidents per cause. The figures show there has been an increase in the 5 year moving average for the corrosion and construction defects while there has been a decrease in external interference incidents.

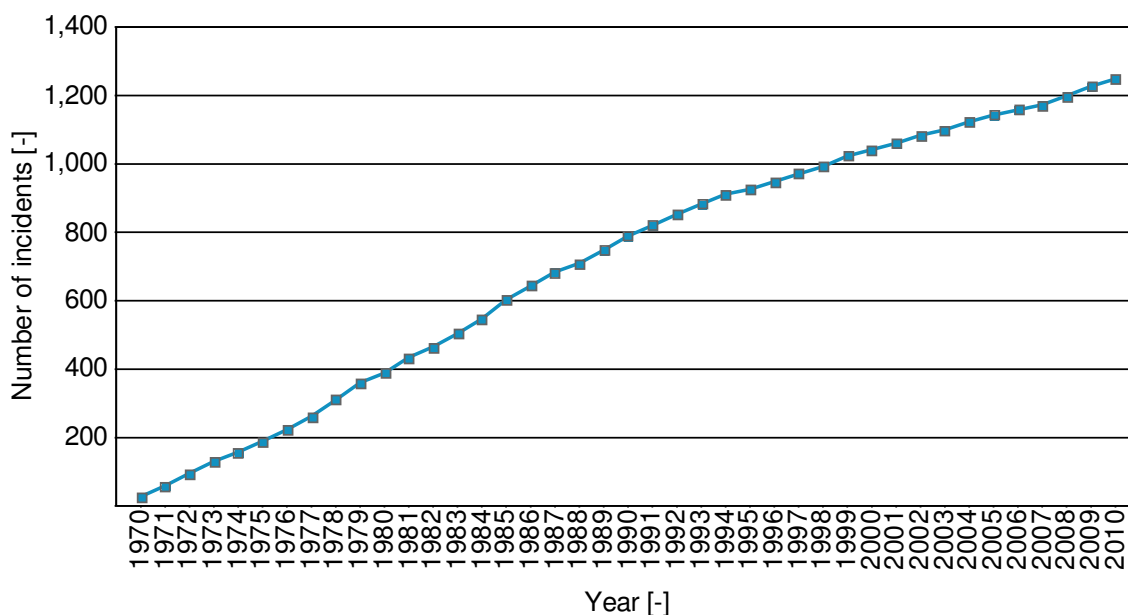
In Figure 12 the cumulative number of incidents are depicted.



**Figure 10: Annual number of incidents**



**Figure 11: Number of incidents 5 year moving average**



**Figure 12: 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 12) 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.

The EGIG has compared the primary failure frequencies of different periods, namely the total period (1970-2010), the period corresponding to the seventh EGIG report (1970-2007), a period of 40 years, 30 years, 20 years, 10 years and the period of the last 5 years (2006-2010).

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 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 [km·yr] | Primary failure frequency per 1000 km·yr |
|-------------|---------------------------------|-------------------------|-------------------------------|------------------------------------------|
| 1970 - 2007 | 7 <sup>th</sup> report 38 years | 1173                    | $3.15 \cdot 10^6$             | 0.372                                    |
| 1970 - 2010 | 8 <sup>th</sup> report 41 years | 1249                    | $3.55 \cdot 10^6$             | 0.351                                    |
| 1971 - 2010 | 40 years                        | 1222                    | $3.52 \cdot 10^6$             | 0.347                                    |
| 1981 - 2010 | 30 years                        | 860                     | $3.01 \cdot 10^6$             | 0.286                                    |
| 1991 - 2010 | 20 years                        | 460                     | $2.25 \cdot 10^6$             | 0.204                                    |
| 2001 - 2010 | 10 years                        | 207                     | $1.24 \cdot 10^6$             | 0.167                                    |
| 2006 - 2010 | 5 years                         | 106                     | $0.654 \cdot 10^6$            | 0.162                                    |

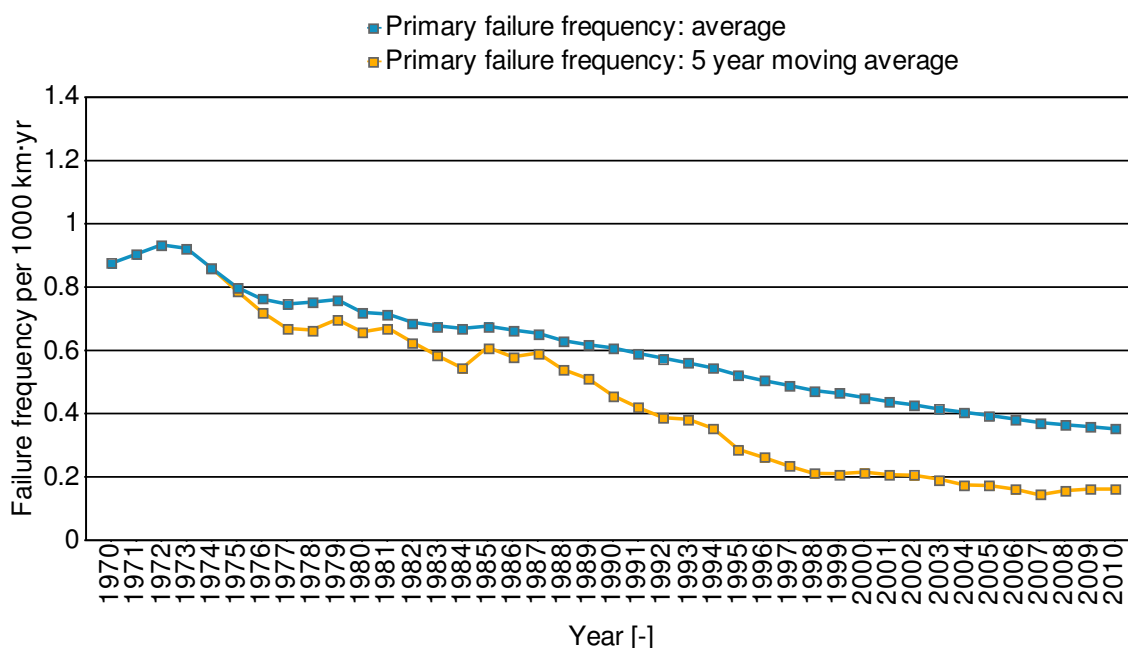
**Table 1: Primary failure frequencies**

In 2010 the primary failure frequency over the entire period was equal to 0.35 per 1,000 km·yr. An observation is that the overall failure frequency (0.35) over the entire period (1970-2010) is slightly lower than the failure frequency of 0.37 reported in the 7<sup>th</sup> EGIG (1970-2007).

The primary failure frequency over the last five years was, in 2010, equal to 0.16 per 1,000 km·yr. The failure frequency over the past five years is approximately half the primary failure frequency over the entire period showing the improved performance over recent years.

Figure 13 shows the evolution of the primary failure frequencies over the entire period and the last five years.

Figure 13 illustrates the steady drop of the primary failure frequencies and the failure frequencies of the 5 years moving average. The primary failure frequency over the entire period declined from 0.87 per 1,000 km·yr in 1970 to 0.35 per 1,000 km·yr in 2010. The moving average primary failure frequency over five years decreased by a factor 5 (0.86 to 0.16 per 1,000 km·yr).

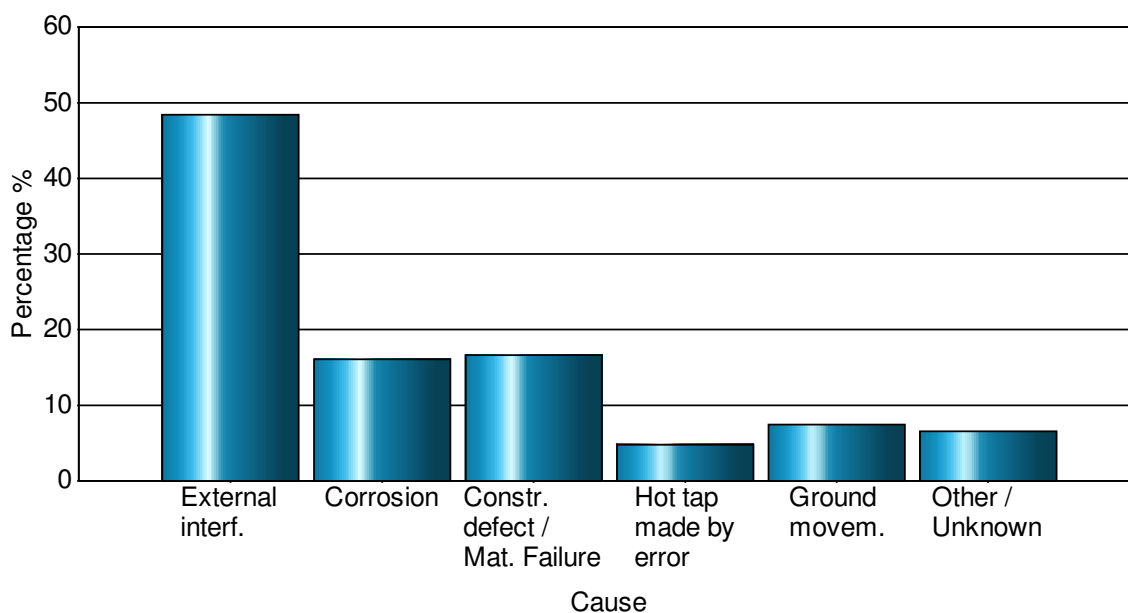


**Figure 13: Primary failure frequencies**

Six different causes have been identified and are given in Table 2 and Figure 14 in association with the percentage of incidents they represent. External interference remains the main cause of incidents.

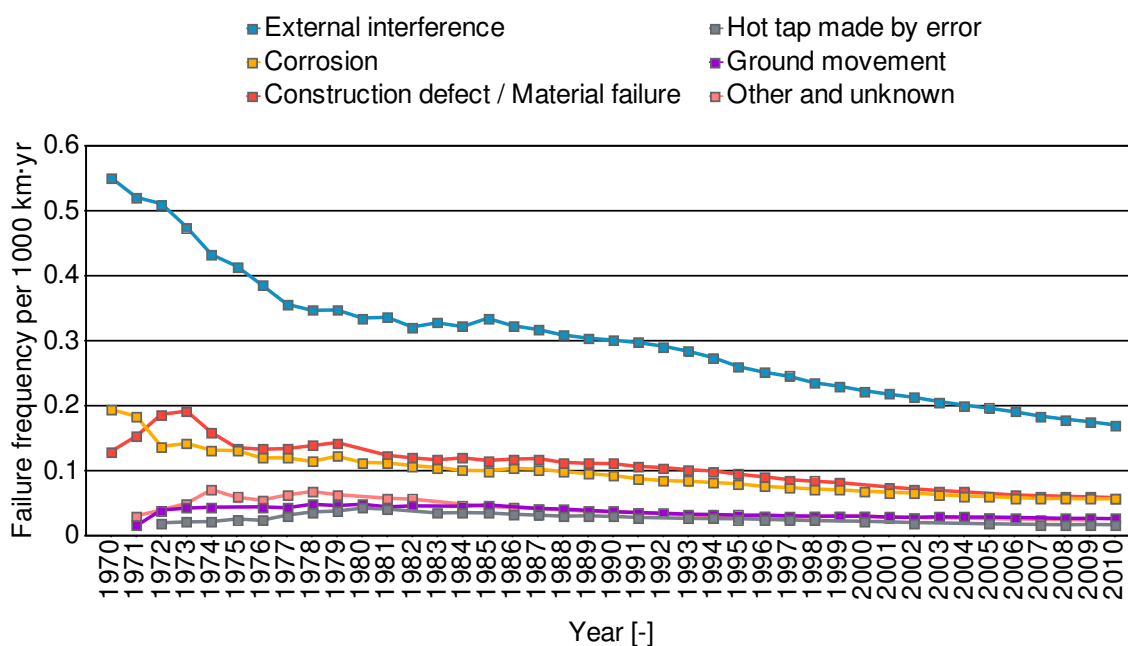
| Cause                                  | Distribution [%] |
|----------------------------------------|------------------|
| External interference                  | 48.4             |
| Construction defect / Material failure | 16.7             |
| Corrosion                              | 16.1             |
| Ground movement                        | 7.4              |
| Hot-tap made by error                  | 4.8              |
| Other and unknown                      | 6.6              |

**Table 2: Distribution of incident per cause.**

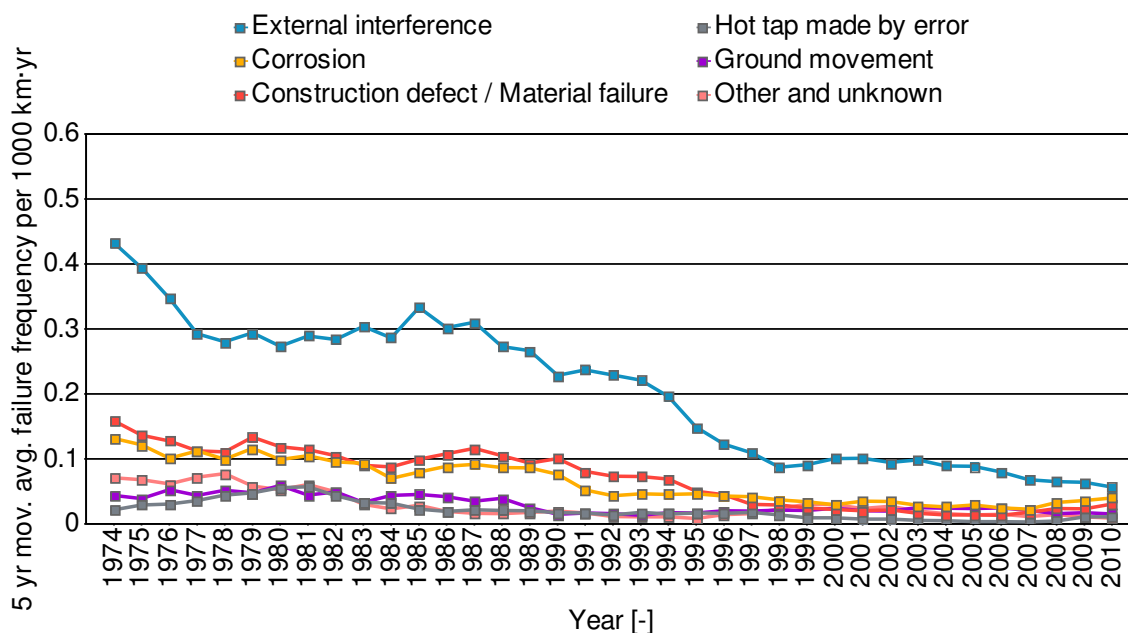


**Figure 14: Distribution of incidents per cause**

Figure 15 and Figure 16 give respectively the primary failure frequencies for the entire period (up to the year) and for the last five years moving average per cause.



**Figure 15: Primary failure frequencies per cause (up to the year)**



**Figure 16: Primary failure frequencies per cause (5-years moving average)**

Figure 15 illustrates the reducing failure frequency over the years. This has been due to technological developments, such as: welding, inspection, condition monitoring using in-line inspection and improved procedures for damage prevention and detection.

As far as the cause of external interference is concerned, its associated primary failure frequency over the period 1970-2010 decreased to 0.17 per 1,000 km·yr while the 5-years moving average has levelled off at around 0.1 per 1,000 km·yr since 1997. From 2003 the 5-years moving average of the external interference is gradually decreasing from 0.10 to 0.06. However external interference remains the main cause of incidents, but the differences with incidents of other causes, especially corrosion and construction defects/ material failures are small.

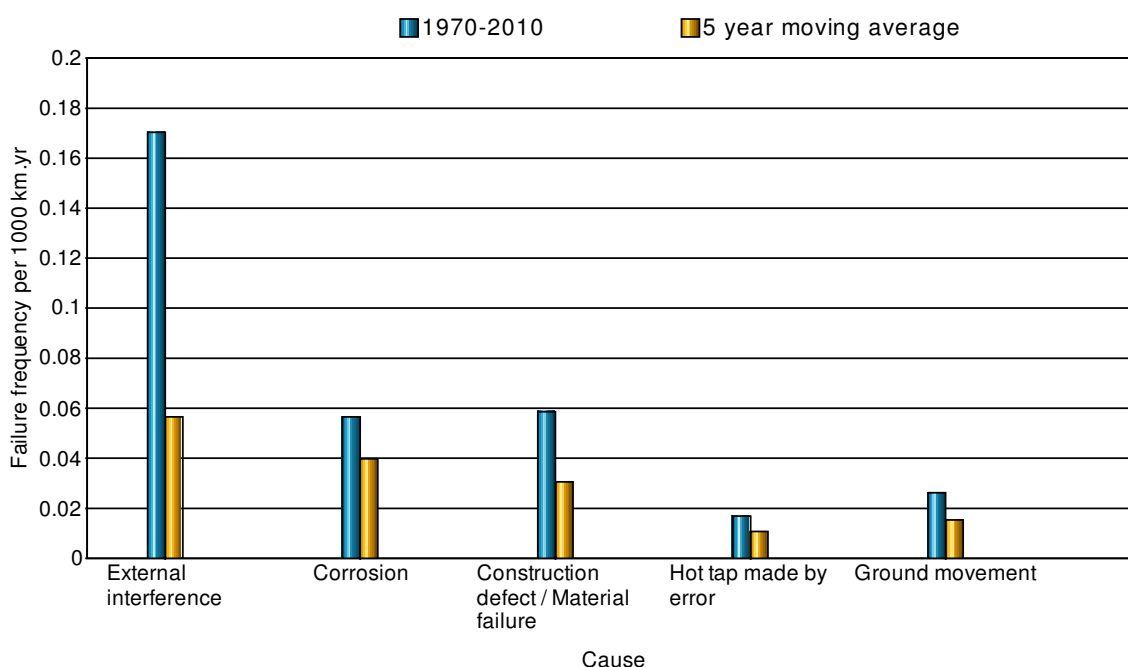
Improvements in the prevention of external interference incidents are obtained through a more stringent enforcement of land use planning, the application of one-call systems for the digging activities of external parties (in several counties there is now a legal requirement to report digging activities) with the adoption of appropriate actions by the gas companies like supervision or marking of the pipeline in the direct neighbourhood of the digging activities.

In Table 3 the primary failure frequencies and the 5 year moving average of these frequencies are given for the year 2010 (for confidence intervals see APPENDIX 1).

| Cause                                  | Primary failure frequency      |                                            |
|----------------------------------------|--------------------------------|--------------------------------------------|
|                                        | 1970-2011<br>per<br>1000 km.yr | 5 year moving average<br>per<br>1000 km.yr |
| External interference                  | 0.170                          | 0.057                                      |
| Corrosion                              | 0.057                          | 0.040                                      |
| Construction defect / Material failure | 0.059                          | 0.031                                      |
| Hot tap made by error                  | 0.017                          | 0.011                                      |
| Ground movement                        | 0.026                          | 0.015                                      |

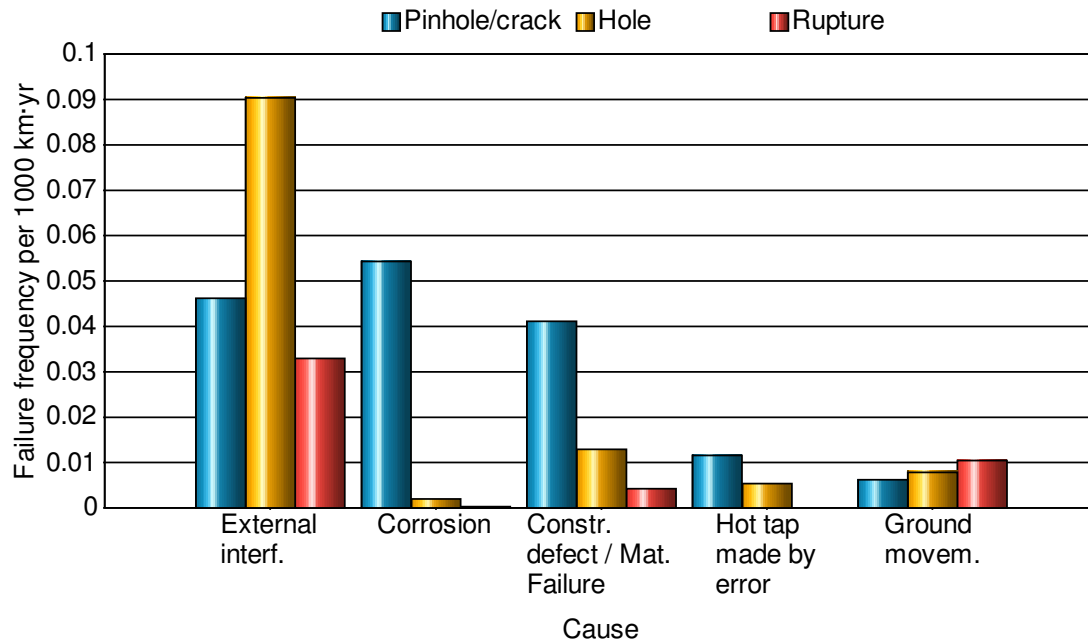
Table 3: Primary failure frequencies per cause

Figure 17 illustrates the link between the causes and the type of incident in terms of size of leak.



**Figure 17: Relation primary failure frequency and cause**





**Figure 18: Relation primary failure frequency, cause and size of leak (period 1970 - 2010)**

Figure 18 shows that over the whole period the bigger leak sizes (holes and ruptures) are especially caused by external interference, which is also the most common cause (approximately 50% of the incidents), followed by ground movement.

### 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.

The calculation of secondary failure frequencies is done to consider the influence of 'design parameters' (pressure, diameter, depth of cover, etc.) on the causes and consequences of the incidents.

For six damage causes relevant for the EGIG database the most appropriate secondary failure frequencies have been calculated according to the following design parameters:

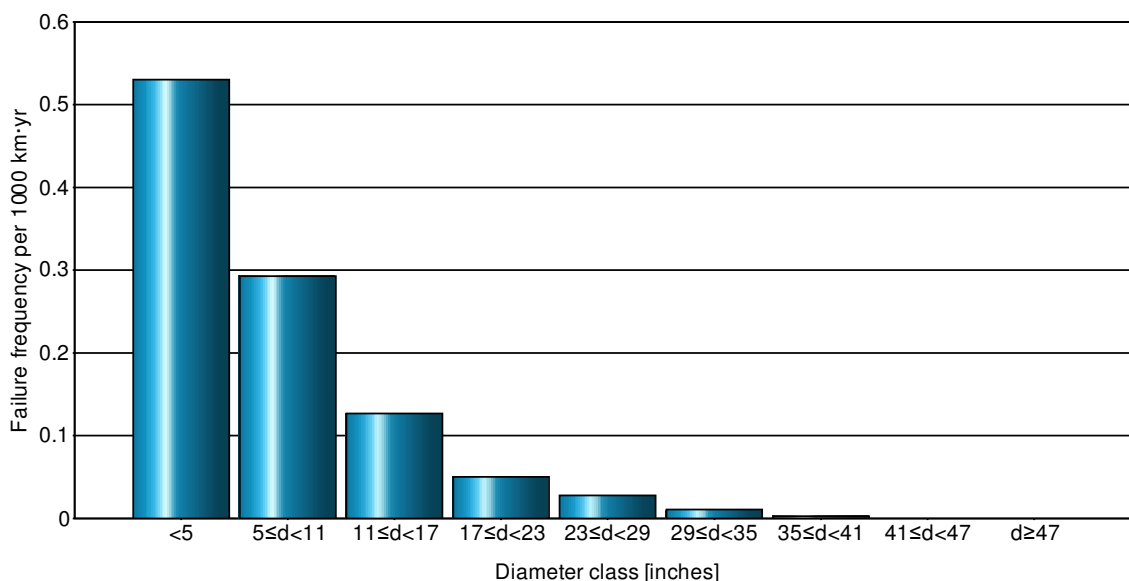
- External interference: the diameter of the pipeline, the depth of cover and the wall thickness.
- Corrosion: the year of construction, the type of coating and the wall thickness.
- Construction defect/material failure: the year of construction.
- Hot tap made by error: the diameter of the pipeline.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

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

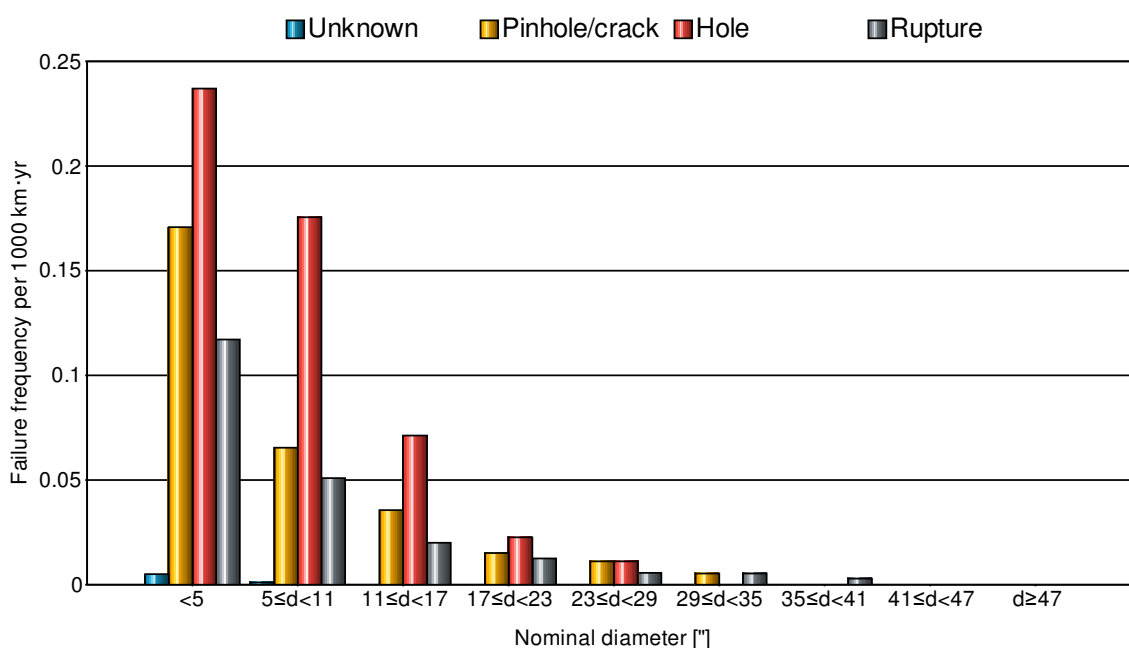
### 3.3.3.1 *Relation between external interference, size of leak and design parameter*

Figure 19 to Figure 24 show the relation between the consequences of the incidents caused by external interferences and the diameter of the pipeline, the depth of cover and the wall thickness. In this report for each design parameter two graphs are constructed: the first graph presents the data for each of the classes within one design parameters, the second graphs gives a further breakdown of the individual classes as a function of the leak size.

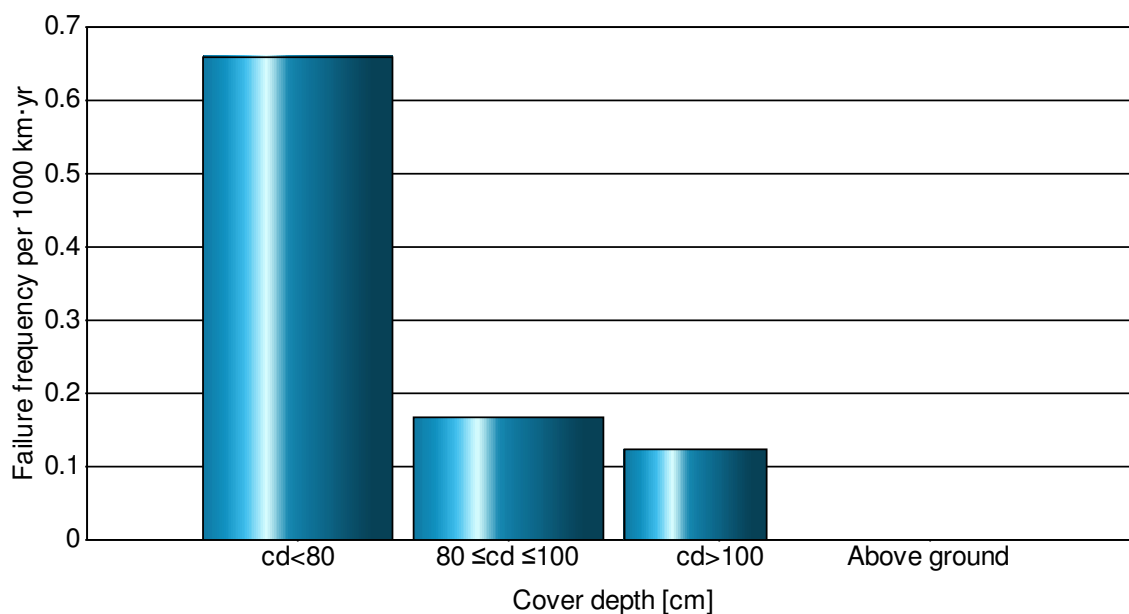
Although the graphs are presented separately it must be noticed that the design parameters are correlated. No quantitative correlations between parameters have been studied.



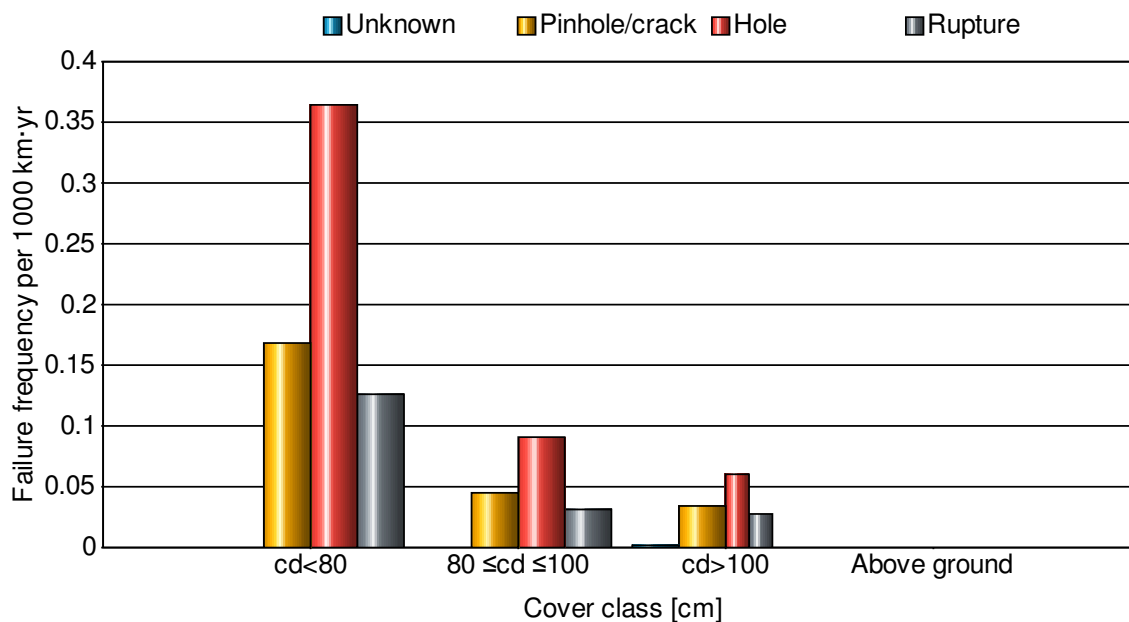
**Figure 19: Relation external interference and diameter (d) class**



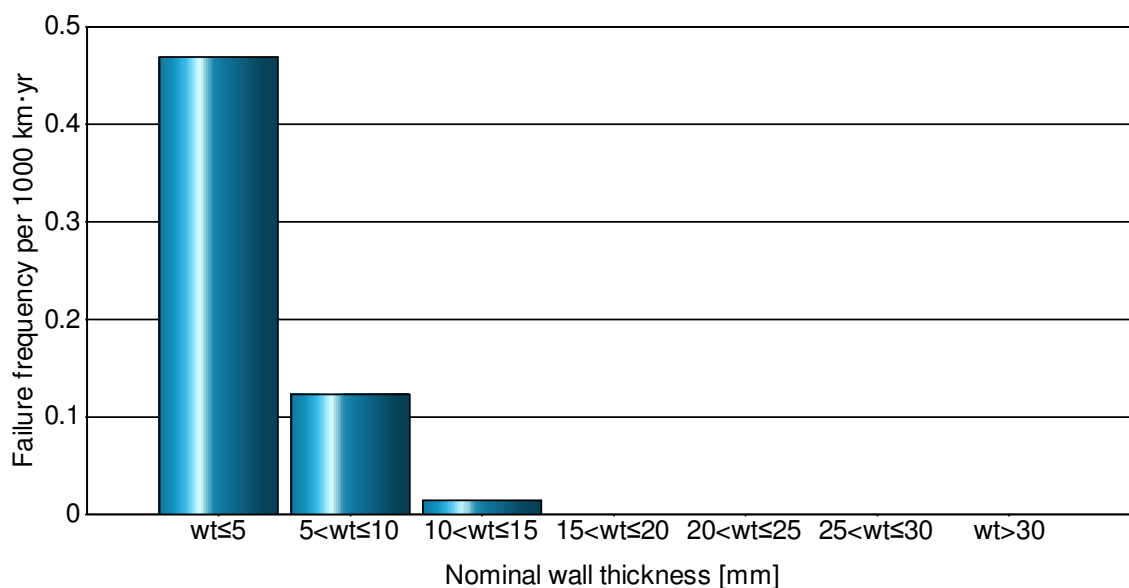
**Figure 20: Relation external interference, size of leak and diameter (d) class**



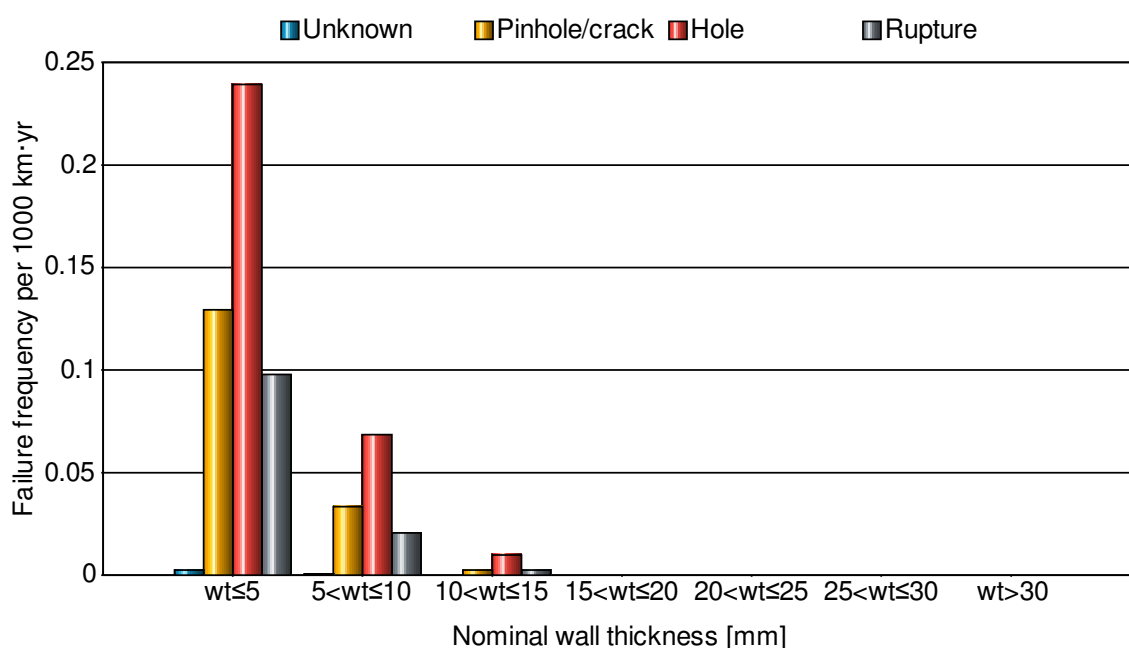
**Figure 21: Relation external interference and depth of cover (cd) class**



**Figure 22: Relation external interference, size of leak and depth of cover (cd) class**



**Figure 23: Relation external interference and wall thickness (wt) class**



**Figure 24: Relation external interference, size of leak and wall thickness (wt) class**

From these figures some general conclusions can be drawn:

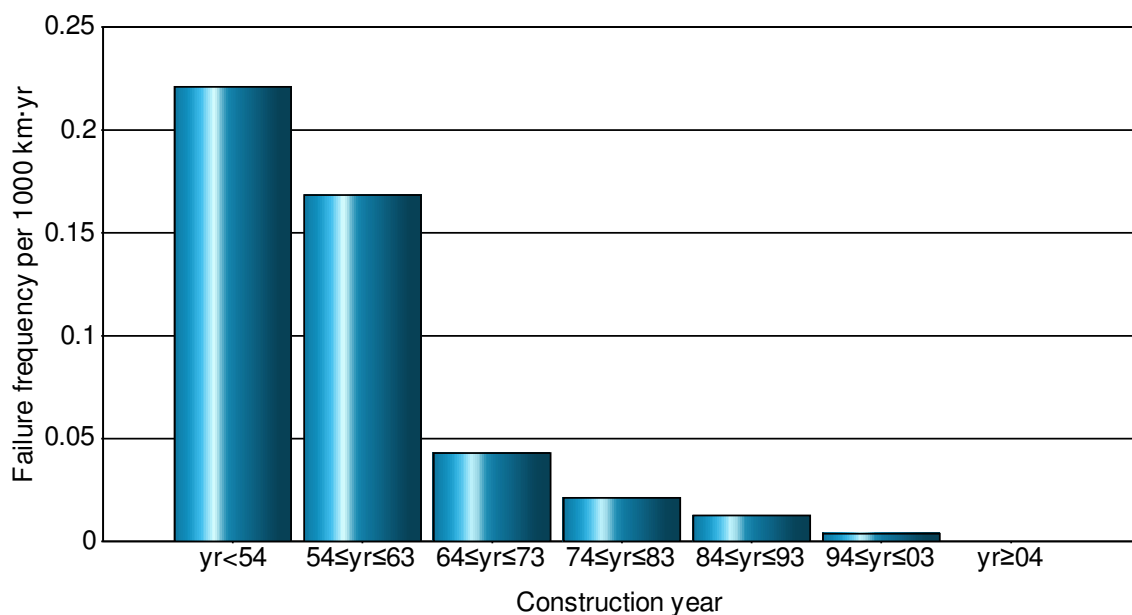
- The first conclusion (Figure 19) is that small diameter pipelines are more vulnerable to external interferences than bigger diameter pipelines. This can be explained by the fact

that small diameter pipelines can be more easily hooked up during ground works than bigger pipelines, the second reason is that their resistance is often lower due to thinner wall thickness.

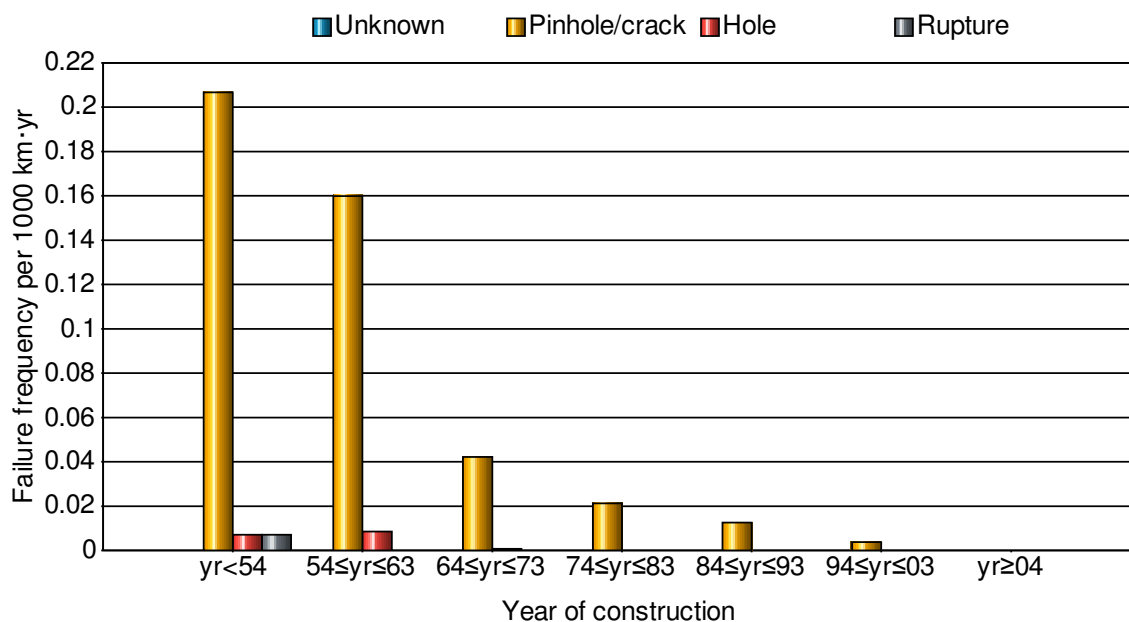
- The second conclusion is that the depth of cover is one of the leading indicators for the failure frequencies of pipelines. The general rule is that pipelines with a larger depth cover will have a lower primary failure frequency (Figure 21).
- It seems that wall thickness is an effective protective measure against the impact of external interferences.
- The more severe incidents like ruptures and holes occurs mainly at pipelines with smaller diameters, a relative small cover depth and with the pipelines with a small wall thickness (see Figure 20, Figure 22, Figure 24).

### 3.3.3.2 *Relation between corrosion, size of leak and design parameter*

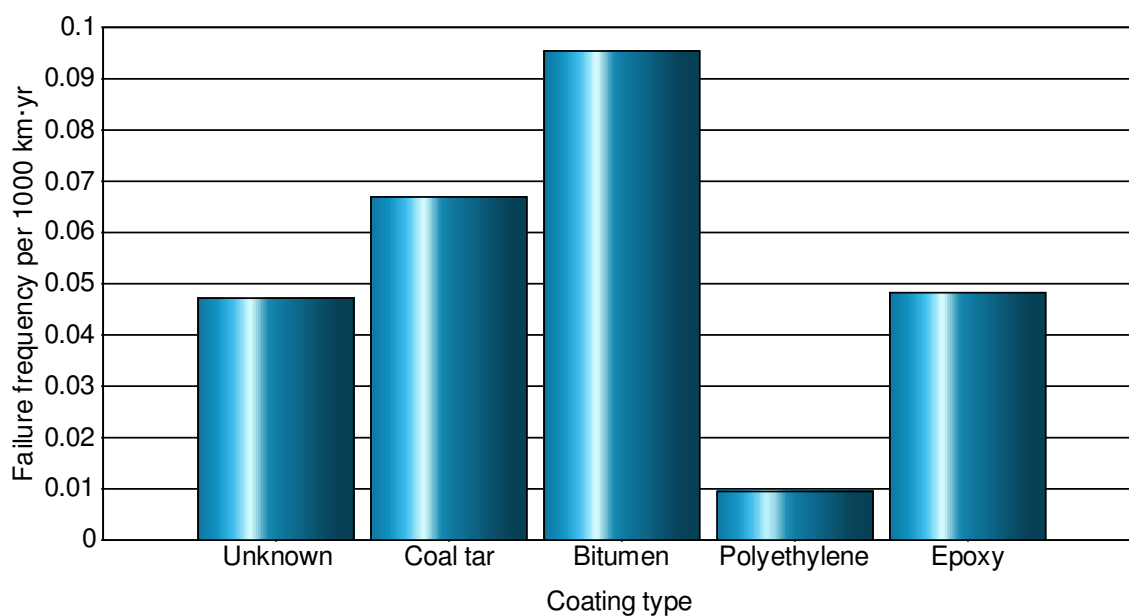
Figure 25 to Figure 30 show the relation between the failure frequencies of incidents caused by corrosion and the year of construction of the pipeline, the type of coating and the wall thickness. The failure frequencies of these design parameters are also presented as a function of the leak size.



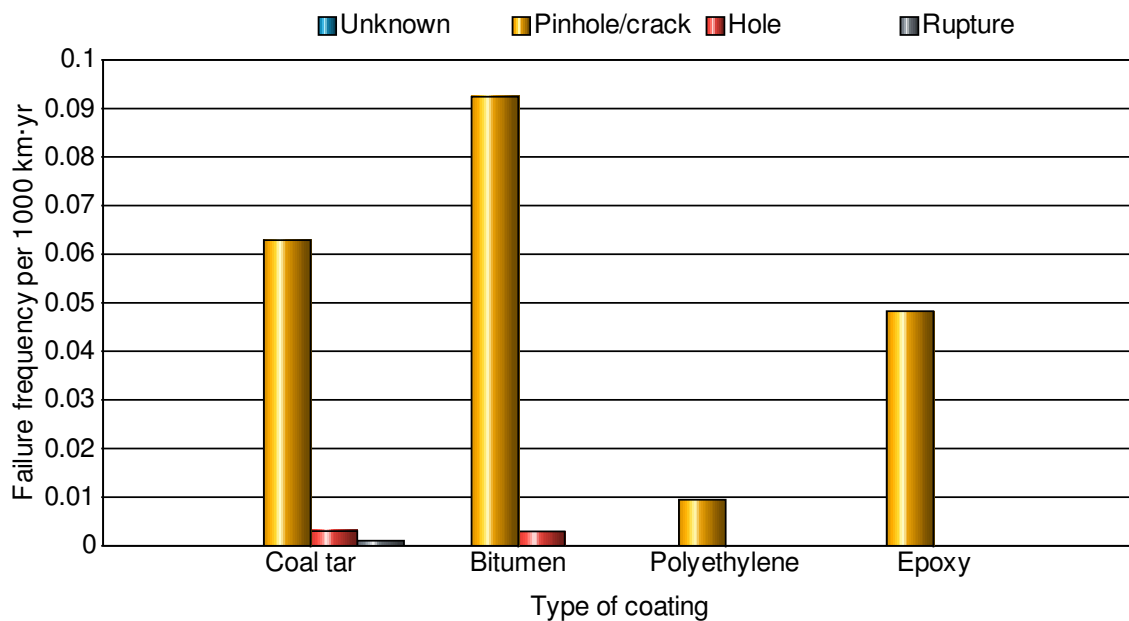
**Figure 25: Relation corrosion and year of construction (yr) class**



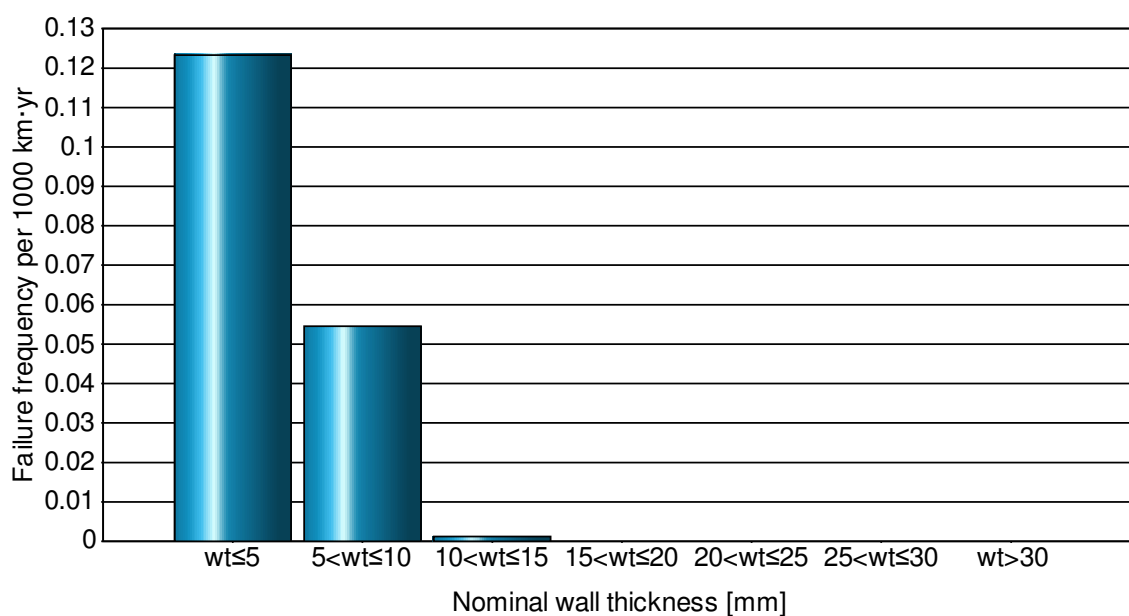
**Figure 26: Relation corrosion, size of leak and year of construction (yr) class**



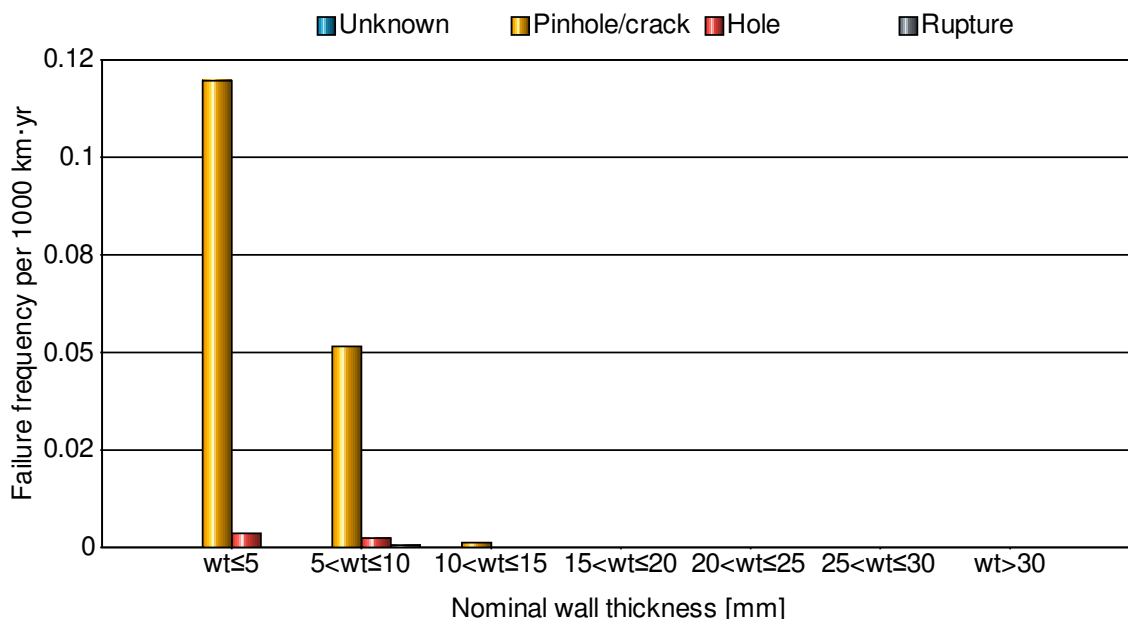
**Figure 27: Relation corrosion and most common type of coating**



**Figure 28: Relation corrosion, size of leak and most common type of coating**



**Figure 29: Relation corrosion and wall thickness (wt) class**



**Figure 30: Relation corrosion, size of leak and wall thickness (wt) class**

Corrosion has been identified as the third most common cause of incidents (16%). Figure 18 and Figure 25 to Figure 30 show that corrosion often results in smaller leak sizes (pinholes and cracks), whereas very few holes were observed and only one rupture occurred on a pipeline, which was constructed before 1954. This rupture was caused by internal corrosion of a pipeline originally used for the transportation of coke oven gas.

Figure 25 illustrates the link between the year of construction of the pipelines and the failure frequencies whereas Figure 27 shows the relation between the most common type of coatings and the failure frequencies. From these figures it seems that older pipelines, with predominantly tar coatings, will have higher failure frequencies.

Corrosion is a 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, as Figure 29 illustrates. The failure point of a thinner pipeline is reached more quickly. Corrosion on thicker pipelines takes longer before causing an incident and therefore has more chance to be detected. 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.

Three types of corrosion have been addressed by the EGIG: external corrosion, internal corrosion and corrosion with an unknown cause. External corrosion is located at the external surface of the pipe while internal corrosion is located at the internal surface of the pipe. Up to 2010 they represent:

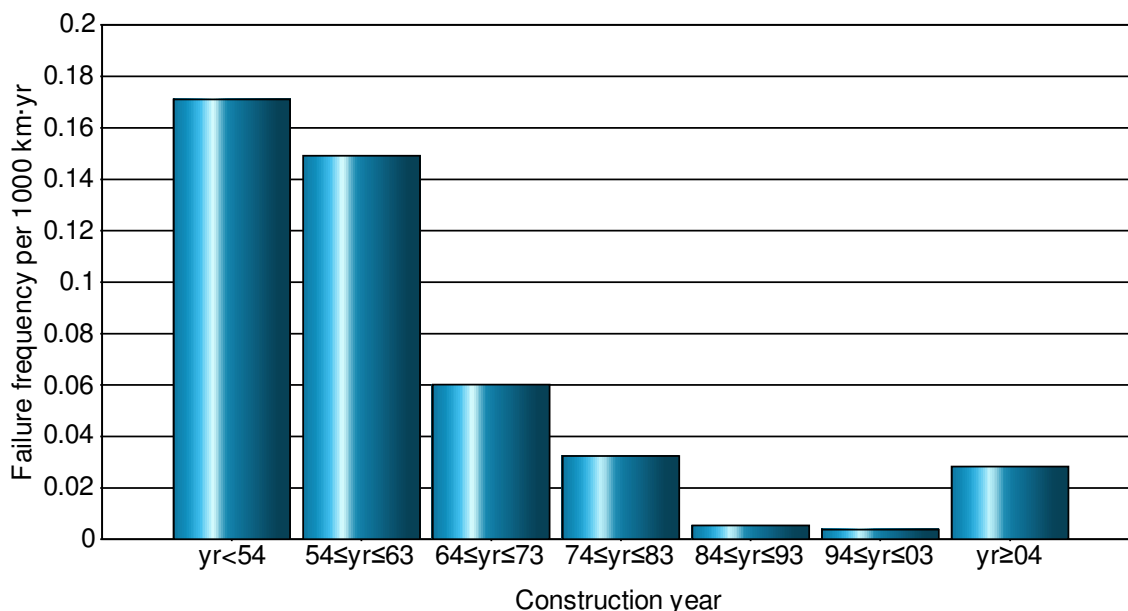
| Corrosion type | Distribution of corrosion incidents [%] |
|----------------|-----------------------------------------|
| External       | 83                                      |
| Internal       | 13                                      |
| Unknown        | 4                                       |

**Table 4: Distribution corrosion incidents.**

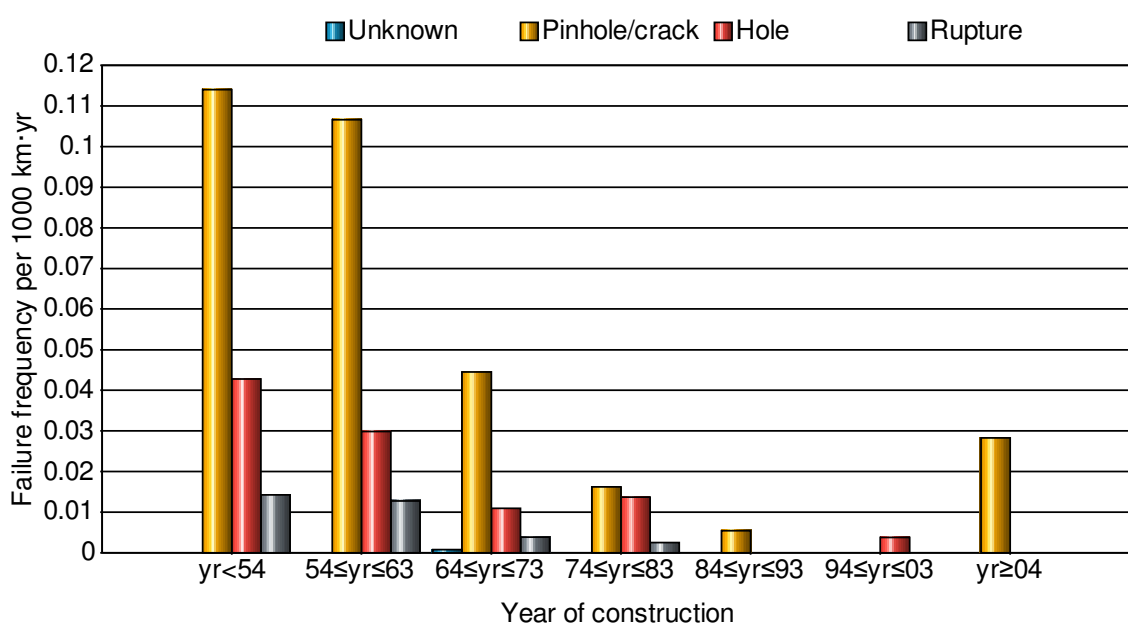


63% of the cases of external corrosion was due to pitting. Galvanic corrosion represents 14%. Unknown causes represent 14% of the external corrosion incidents whereas stress corrosion cracking was responsible for only 8%. Approximately 74% of the internal corrosion incidents were caused by stress corrosion cracking.

### 3.3.3.3 *Relation between construction defect, size of leak and design parameter*



**Figure 31: Relation construction defect/material and year of construction (yr) class**



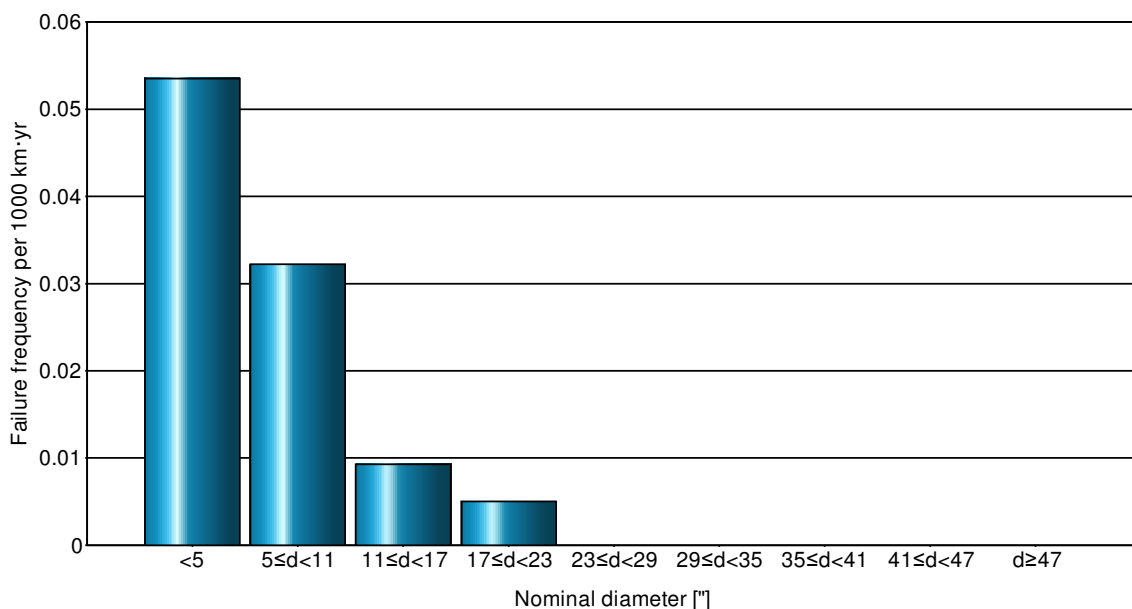
**Figure 32: Relation construction defect/material, size of leak and year of construction (yr) class**

Figure 31 shows that the older the pipelines, the higher the failure frequencies (due to construction defect/material). It seems that the new pipelines are less vulnerable to construction defect/material, which is synonymous to technical improvements. This phenomenon has also been observed in the ageing analysis (see paragraph 3.4.1)

Figure 31 and Figure 32 shows that the failure frequency of the class ' $\geq 2004$ ' seems high. This failure frequency is caused by 1 incident with a small amount of pipeline exposure giving a high unreliability.

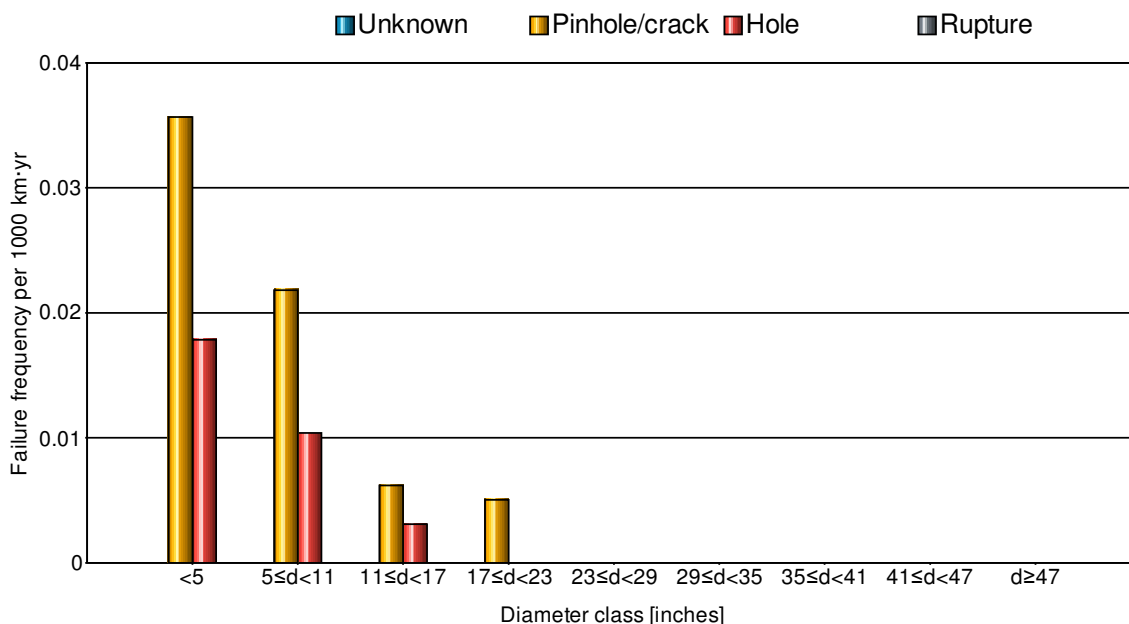
### 3.3.3.4 *Relation between hot tap made by error, size of leak and design parameter*

The term "hot tap made by error" means that a connection has been made by error to a gas transmission pipeline.



**Figure 33: Relation hot tap made by error and diameter class**

Figure 33 illustrates that larger diameter pipelines are less vulnerable to hot tap in error. Figure 34 shows that this kind of error can lead not only to small size of leak (pinholes), but also to large size of leak (holes), especially with very small diameter pipelines.

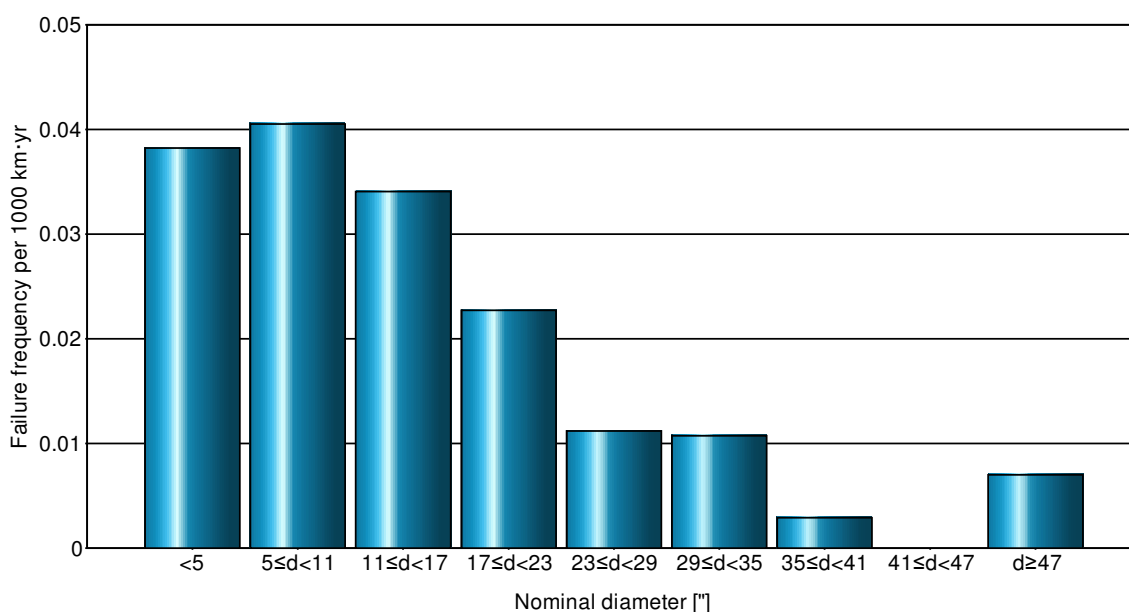


**Figure 34: Relation hot tap made by error, size of leak and diameter class**

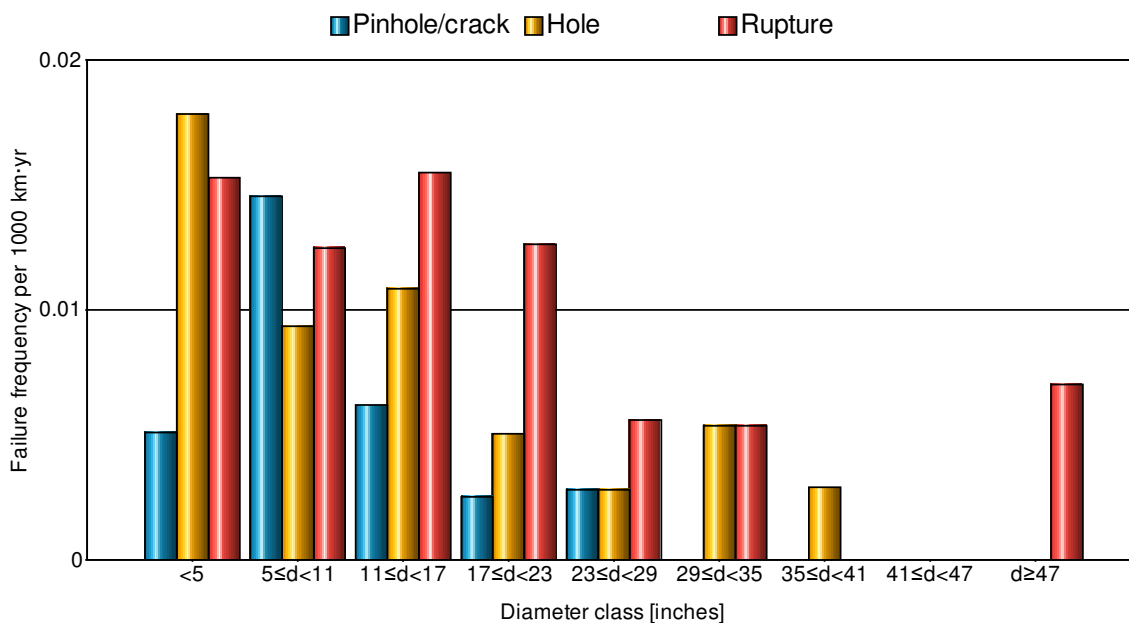
### 3.3.3.5 Ground movement

Ground movement is responsible for 7.5% of the total incidents of the database.

Figure 35 and Figure 36 depicts the relation between ground movement, size of leak and diameter class. Ground movement incidents can cause serious leak sizes, however, it also can be concluded that smaller diameters are more vulnerable for ground movement than larger diameters. The bar at the diameter  $\geq 47''$  is caused by one ground movement incident. This demonstrates that even large diameter pipelines can be affected by the enormous forces accompanied by ground movement incidents.



**Figure 35: Relation ground movement and diameter class**



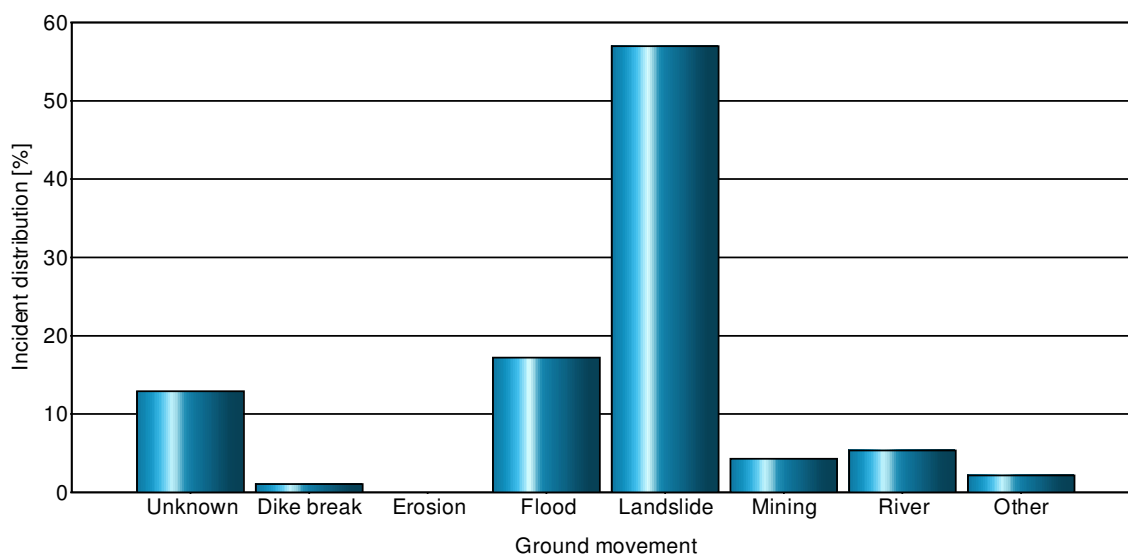
**Figure 36: Relation ground movement, size of leak and diameter class**

Analysing the information recorded about these failure causes, it is possible to highlight some important elements, which are divided into "Ground Movement".

The sub-causes for ground movement are:

- Landslide
- Flood
- River
- Mining
- Dike break
- Erosion
- Other
- Unknown

Figure 37 shows the distribution of the sub-causes in the category ground movement.



**Figure 37: Distribution of the sub-causes of ground movement**

### 3.3.3.6 *Other and unknown*

The main cause for the category “Other and unknown” is lightning.

The sub-cause lightning represents almost 26% of the incidents within this category.

Within the period 1970-2010, 21 incidents due to lightning have been recorded in the EGIG database, which represents a failure frequency due to lightning equal to 0.0059 per 1,000 km·yr.

The EGIG examined the distribution of the consequences of lightning in terms of leak sizes.

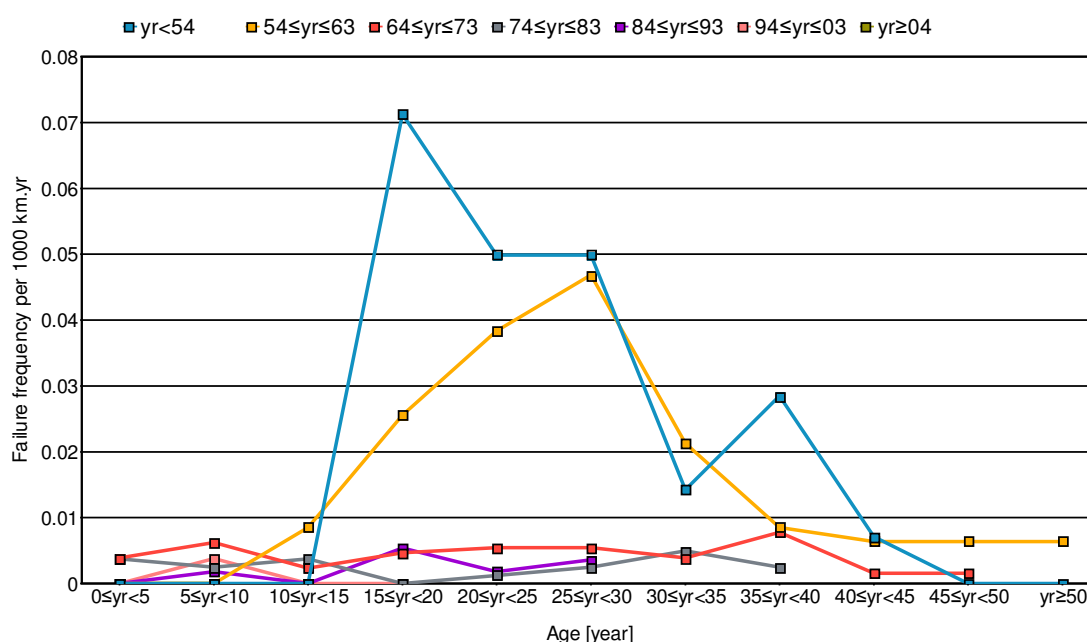
Out of 21 incidents, 19 were small leaks (pinholes and cracks) and only 2 resulted in a large leak (hole). As lightning is a huge source of energy, ignition is very likely (see section 3.4.3).

### 3.4 Other analysis

#### 3.4.1 Ageing

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

In this ageing analysis, the failure frequency of corrosion incidents has been studied as a function of construction year.



**Figure 38: Ageing analysis (corrosion)**

**Explanation** Figure 38.

Taking for instance a pipeline constructed before 1954, the failure frequency 25 to 30 years after the construction year is equal 0.050 whereas it will equal 0.014 after 35-40 years.

The first conclusion of Figure 38 is that early constructed pipelines (before 1964) have indeed a higher failure frequency than recently constructed pipelines. However a second important conclusion is that all failure frequencies irrespective of the age category are slightly decreasing in time.

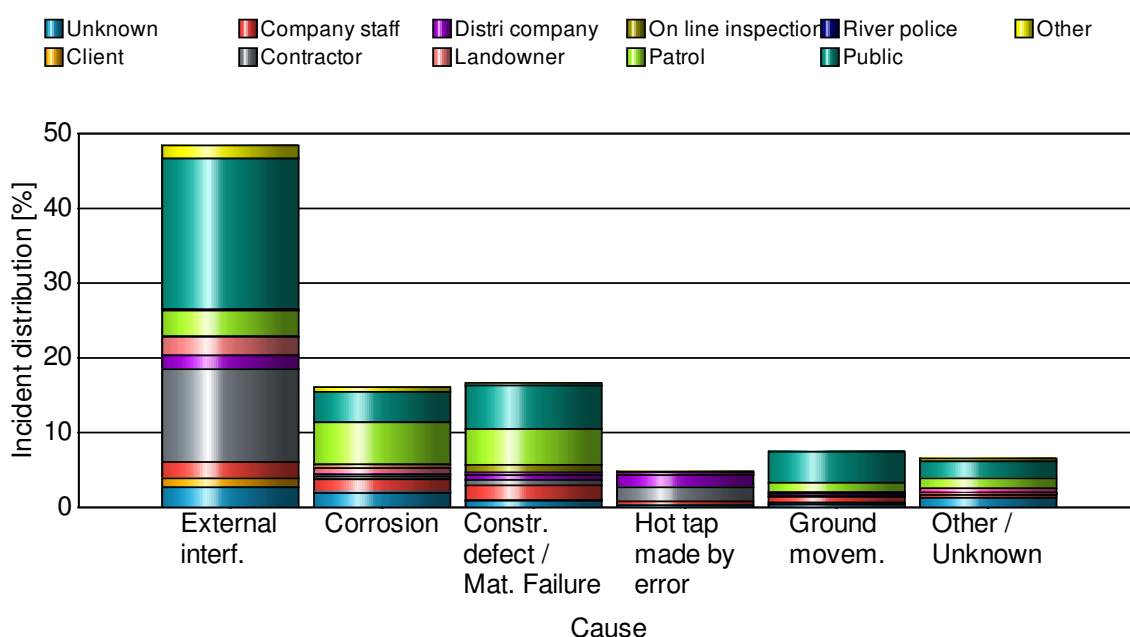
Pipelines constructed, commissioned and operated before 1960s appear to be subject to failure due to corrosion. When technology became available during the 1960s, it appears that pipelines operated afterwards have not had a history of failures due to corrosion. Pipelines constructed from the 1964-1973 construction class do not show ageing. Operational measures for older pipelines have tended to reduce the failure frequency of the older pipelines.

### 3.4.2 Detection of incidents

Table 5 shows the distribution of the type of detection. The public is the most common detector, with almost 37% of the incidents. Up to 2010 almost 17% of the incidents were detected by the patrols.

| Detection            | Incident distribution |
|----------------------|-----------------------|
| Public               | 36.7                  |
| Patrol               | 16.5                  |
| Contractor           | 15.6                  |
| Unknown              | 7.5                   |
| Company staff        | 7.5                   |
| Distribution company | 4.8                   |
| Landowner            | 4.6                   |
| Other                | 3.3                   |
| Client               | 1.7                   |
| On line inspection   | 1.6                   |
| River police         | 0.2                   |

**Table 5: Detection of incidents**



**Figure 39 Detection of incidents per cause**

Figure 39 demonstrates the detection of incidents per cause. It can be seen that most incidents are detected by the public. For external interference public and contractors are the most important parties for detection. Patrols organised by the transmissions companies seems to be an effective measure for the detection of incidents with the cause corrosion and construction defect.

### 3.4.3 Ignition probability

Fortunately not every gas release ignites, which limits the consequences of the incidents. In the period 1970-2010, only 4.5% of the gas releases recorded as incidents in the EGIG database ignited.

Ignition depends on the existence of random ignition sources. The EGIG database gives the possibility to evaluate the link between ignition and leak size. Table 6 gives the ignition probabilities per size of leak.

| Size of leak  | Ignition probabilities [%] |
|---------------|----------------------------|
| Pinhole-crack | 4                          |
| Hole          | 2                          |
| Rupture       | 13                         |

**Table 6: Ignition probabilities per leak type**

Ruptures with ignition can cause severe societal damage. This is especially the case for pipelines with larger diameters. Table 7 clearly shows that gas releases from big diameter pipelines are more likely to ignite than releases from smaller diameter pipelines. It can be noticed that the larger diameter pipelines are also more likely to be higher in pressure.

| Size of leak        | Ignition probabilities [%] |
|---------------------|----------------------------|
| Rupture < 16 inches | 10                         |
| Rupture ≥ 16 inches | 33                         |

**Table 7: Ignition probabilities for ruptures at different pipeline diameters.**

This previous table gives the ignition probabilities of all incidents together irrespective of their causes. It is obvious that these probabilities vary according to their causes. The EGIG specifically looked at the ignition probabilities of gas releases caused by lightning.

Out of 21 gas releases in the period 1970-2010 caused by lightning, 12 ignited, which brings the ignition probability of gas releases due to lightning up to 57%.

### 3.4.4 Injuries and fatalities

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

The data base of EGIG only contains qualitative information about the consequences of incidents. The EGIG data base contains a total of 1249 incidents. In 7 cases (0.6% of the population) these incidents gave fatalities. Fatalities to the public only occurred in 2 cases (0.2% of the population).



The probability of severe consequences has obviously a relation with the probability of vulnerable dwellings around the affected pipeline.

#### **4 CONCLUSIONS AND FACTS**

- EGIG has maintained and expanded the European Gas pipeline incident database. Transmission companies of fifteen European countries now collect incident data on more than 135,000 km of pipelines every year. The total exposure, which expresses the length of a pipeline and its period of operation, is 3.55 million km·yr.
- The statistics of incidents collected in the database give reliable failure frequencies. The overall incident frequency is equal to 0.35 incidents per year per 1,000 km over the period 1970 to 2010.
- The 5 year moving average failure frequency in 2010, 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 has reduced consistently over the years, although it has tended to stabilise.
- The high contribution of external interference emphasises its importance to pipeline operators and authorities.
- External interference incidents are characterised by potentially severe consequences.
- External interference incidents have reduced over the years so that they are now of a similar order to that of corrosion and construction/material defects.

#### **5 REFERENCE**

- 7th Report of the **E**uropean **G**as Pipeline **I**ncident Data **G**roup, 1970-2007, December 2008.

## APPENDIX 1: STATISTICS

*Primary failure frequencies over different time intervals*

| Period      | Interval [years]                | Number of incidents [-] | Total system exposure [km·yr] | Primary failure frequency per 1000 km·yr | 95% LL primary failure frequency per 1000 km·yr | 95% UL primary failure frequency per 1000 km·yr |
|-------------|---------------------------------|-------------------------|-------------------------------|------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| 1970 - 2007 | 7 <sup>th</sup> report 38 years | 1173                    | $3.15 \cdot 10^6$             | 0.372                                    | 0.350                                           | 0.394                                           |
| 1970 - 2010 | 8 <sup>th</sup> report 41 years | 1249                    | $3.55 \cdot 10^6$             | 0.351                                    | 0.332                                           | 0.371                                           |
| 1971 - 2010 | 40                              | 1222                    | $3.52 \cdot 10^6$             | 0.347                                    | 0.328                                           | 0.367                                           |
| 1981 - 2010 | 30                              | 860                     | $3.01 \cdot 10^6$             | 0.286                                    | 0.267                                           | 0.305                                           |
| 1991 - 2010 | 20                              | 460                     | $2.25 \cdot 10^6$             | 0.204                                    | 0.186                                           | 0.224                                           |
| 2001 - 2010 | 10                              | 207                     | $1.24 \cdot 10^6$             | 0.167                                    | 0.145                                           | 0.191                                           |
| 2006 - 2010 | 5                               | 106                     | $0.654 \cdot 10^6$            | 0.162                                    | 0.133                                           | 0.196                                           |

**Table 8: Primary failure frequencies over different time intervals**

| Cause                                  | Primary failure frequency per 1000 km·year | 95% LL Primary failure frequency per 1000 km·year | 95% UL Primary failure frequency per 1000 km·year |
|----------------------------------------|--------------------------------------------|---------------------------------------------------|---------------------------------------------------|
| External interference                  | 0.170                                      | 0.157                                             | 0.184                                             |
| Corrosion                              | 0.057                                      | 0.049                                             | 0.065                                             |
| Construction defect / Material failure | 0.059                                      | 0.051                                             | 0.067                                             |
| Hot tap made by error                  | 0.017                                      | 0.013                                             | 0.022                                             |
| Ground movement                        | 0.026                                      | 0.021                                             | 0.032                                             |

**Table 9: Primary failure frequencies per cause (1970-2010) and their 95% confidence intervals**

| Cause                                  | Primary failure frequency per 1000 km·year | 95% LL Primary failure frequency per 1000 km·year | 95% UL Primary failure frequency per 1000 km·year |
|----------------------------------------|--------------------------------------------|---------------------------------------------------|---------------------------------------------------|
| External interference                  | 0.057                                      | 0.040                                             | 0.078                                             |
| Corrosion                              | 0.040                                      | 0.026                                             | 0.058                                             |
| Construction defect / Material failure | 0.031                                      | 0.019                                             | 0.047                                             |
| Hot tap made by error                  | 0.011                                      | 0.004                                             | 0.022                                             |
| Ground movement                        | 0.015                                      | 0.007                                             | 0.028                                             |

**Table 10: 5-years moving average Primary failure frequencies per cause (situation per 2010)**

## 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 (Ulm, 1990):

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

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

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.

### 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.