New International Failure Frequency Analysis (FFA) Database for Gas Transmission Pipelines

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Quantitative risk assessment (QRA) methodologies for buried onshore natural gas transmission pipelines have become well established in recent years. Although such events are rare, the consequences of high pressure gas pipeline failures can be severe, and it is important for pipeline operators to understand the risks associated with pipelines to manage them effectively. Pipelines are exposed to a wide range of threats, including external interference damage and ground movement which dominate risk for onshore pipelines in the UK. An essential input to any pipeline QRA is the failure frequency for each of the relevant threats that a pipeline is exposed to.

Estimates of pipeline failure frequencies for a pipeline QRA are typically derived either directly from historical data or using Structural Reliability Analysis (SRA) techniques to take account of the pipeline-specific properties (such as operating pressure, diameter and wall thickness), validated against historical data where operational experience exists.

Although pipeline incident databases such as EGIG (European Gas Incident Data Group) and UKOPA (United Kingdom Onshore Pipeline Operators' Association) already exist, the format of the pipeline population data imposes important limitations on the type of analysis that can be performed. The FFA (Failure Frequency Analysis) project was initiated to improve the tools and data available for estimating pipeline failure frequencies from historical data.

Introduction

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Estimates of pipeline failure frequencies for a pipeline QRA are typically derived either directly from historical data or using Structural Reliability Analysis (SRA) techniques to take account of the pipeline-specific properties (such as operating pressure, diameter and wall thickness), validated against historical data where operational experience exists.

The FFA (Failure Frequency Analysis) project was initiated to improve the tools and data available for estimating pipeline failure frequencies from historical data for onshore, below-ground, steel transmission pipelines transporting natural gas at high pressures. Although other pipeline incident databases such as EGIG (European Gas Incident Data Group) [1] and UKOPA (United Kingdom Onshore Pipeline Operators' Association) [2] already exist, the format of the pipeline population is such that analysis can only be performed for each parameter independently. The main objective of the FFA project is to provide a robust data set and analysis methods to enable participating companies to make pipeline failure frequency predictions based on historical data, taking into consideration multiple pipeline-specific parameters. Within the paper, comparisons of key results are made between the EGIG, UKOPA and the FFA databases, where appropriate, to demonstrate the reliability of the FFA database.

Purpose and Structure of the FFA Database

There are currently ten contributing companies in the FFA project, operating natural gas transmission pipelines in the Europe (including the UK), North America and Asia. Pipeline and product loss incident data is currently stored in the FFA database for years from 2008 up to and including 2015. No retrospective data is included for years prior to the commencement of data collection for the database in 2008, due to the difficulty in accessing detailed data for earlier years.

The FFA database has been created using Microsoft Access and has forms for both pipeline population and incident data to be recorded. The parameters used to populate the pipeline data are depicted in the form in Figure 1; a section of pipeline is defined as a length of pipe where these parameter values are unchanged. A change in one or more of these parameters results in a new entry in the database. There are currently 1,308,775 entries in the database representing 1,109,461 km.years of pipeline exposure.

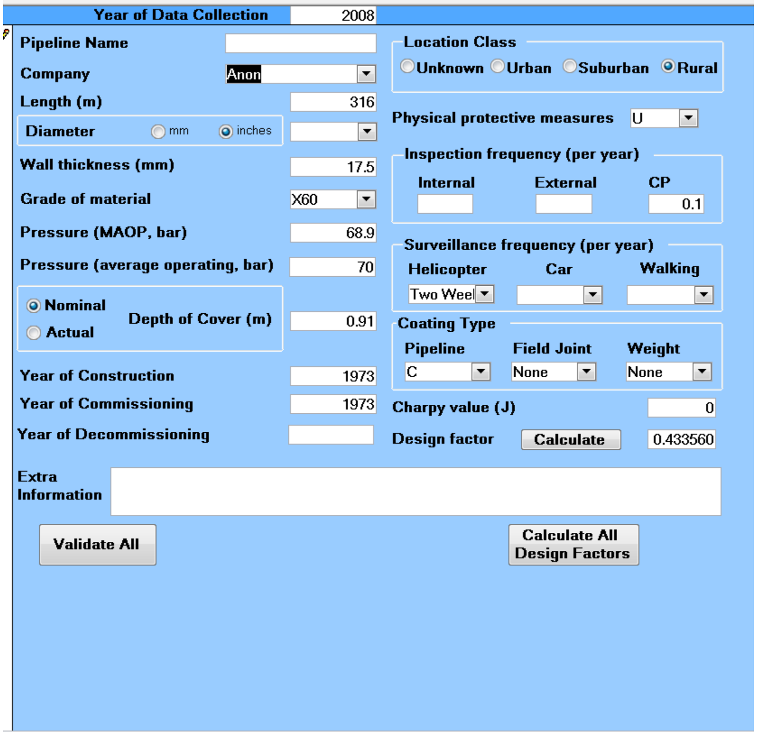


Figure 1: Pipeline population form within the FFA database

A second form, like the pipeline population form, is available within the FFA database for documenting the incident data. This is depicted in Figure 2. This form includes a free field text to allow any additional information about the incident to be recorded; this ensures that data, that may be useful in the future, is not lost. There are currently 114 gas release incidents in the database. For an incident to be recorded in the FFA database, the incident must have led to an unintentional gas release and may be either an ignited or unignited release from an onshore pipeline outside fenced/controlled areas.

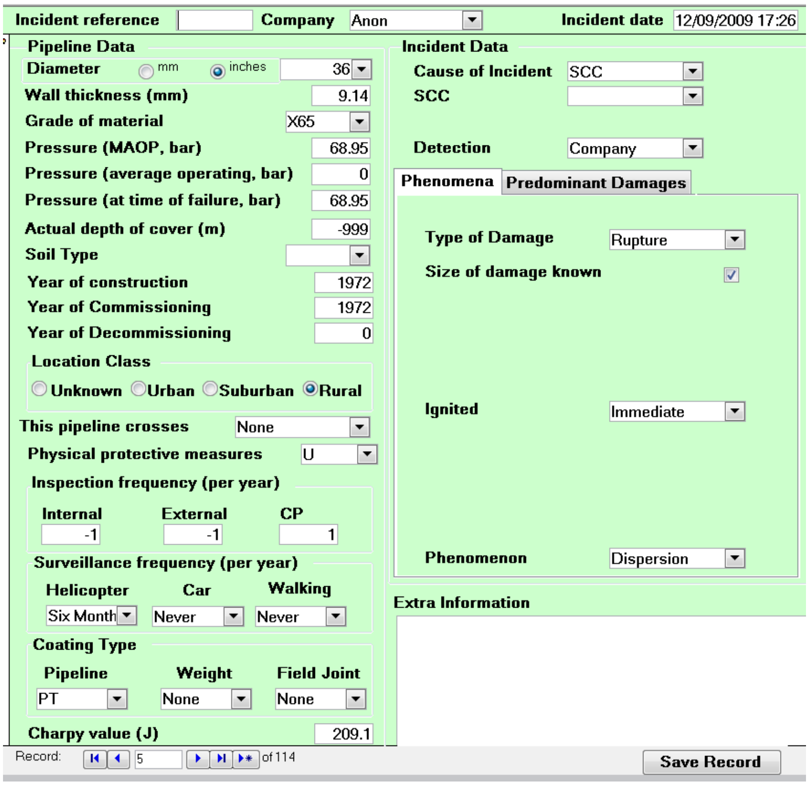


Figure 2: Incident data form within the FFA database

Pipeline and Incident Criteria

When comparing incident databases it is necessary to make sure there is good understanding of the scope of each database and that key incident criteria such as hole size and failure cause are carefully defined in order to ensure agreement between the databases.

For a pipeline to be recorded in the EGIG database, the pipeline must be an onshore steel pipeline with a maximum operating pressure (MAOP) higher than 15 bar and be located outside the fence of a gas installation. Incidents involving equipment or components (e.g. valve, compressor) are not recorded in the EGIG database.

The UKOPA database includes pipelines that carry other hydrocarbon products as well as natural gas. Pipelines must be onshore steel pipelines with an actual operating pressure of 7 bar or greater. Pipelines must be located outside the fences of installations and associated equipment and fittings are not included within the database.

The FFA database requires all onshore steel pipelines with a maximum operating pressure (MAOP) higher than 15 bar outside the fences of gas installations to be recorded and includes failures of pipeline fittings and leaks from flanges directly attached/joined to the pipeline. It should be noted that the FFA database also includes non-European pipeline data whereas the EGIG database contains European pipeline data only. Therefore, where required, a subset of the data within the FFA database will be used for comparison with the EGIG database.

Within pipeline incident databases, incidents are usually classified in terms of their hole size. Within the FFA database, three hole sizes are used; puncture, rip and rupture. It is necessary to carefully define these hole size categories as they will vary by pipeline incident database. For example, the EGIG database also uses three hole sizes but with different names; pinhole/crack, hole and rupture. The UKOPA database requires the actual dimensions of the hole to be recorded and these can then be grouped into pinhole, hole and rupture. In addition, the UKOPA database is unique in that it also includes details of pipeline damage not resulting in a gas release. The hole sizes and corresponding definitions for FFA, UKOPA and EGIG are given in Table 1 for comparison.

As well as defining the hole size categories, it is also of benefit to provide a clear definition for the failure causes. This is documented in Table 2 for the FFA database.

Table 1: Comparison of FFA and EGIG failure mode definitions

FFA Database		**EGIG Database**		**UKOPA Database**	
Hole size	**Definition**	**Hole size**	**Definition**	**Hole size**	**Definition**
Puncture	An approximately circular hole in a pipe, normally small, relative to the pipeline.	Pinhole/ crack	The effective diameter of the hole is smaller than, or equal to, 2 cm.	Pinhole	The effective diameter is smaller than, or equal to, 6 mm.
Rip	A non-circular release, small or large but with a cross-sectional area normally much less than twice the cross-sectional area of the pipe involved.	Hole	The effective diameter of the hole is larger than 2 cm and smaller than, or equal to, the diameter of the pipe.	Hole	The effective diameter of the hole is larger than 6 mm and smaller than the pipe diameter.
Rupture	A large release from a pipe where the cross-sectional area of the release is equal to, or greater than, twice the cross-sectional area of the pipe or a complete break in a pipe.	Rupture	The effective diameter of the hole is larger than the pipeline diameter.	Rupture	The effective diameter of the hole is equal to, or greater than, the diameter of the pipe.

Table 2: FFA failure cause definitions

Failure Cause	Definition
Construction Defects	Mechanical failure associated with weaknesses in the pipe wall due to defects and dents or other weaknesses dating from the original construction activities.
Corrosion	Corrosion covers a range of possible mechanisms such as alternating current (AC)/direct current (DC) – induced corrosion as well as general corrosion resulting in metal loss. Corrosion can occur both internally and externally.
SCC	SCC is Stress Corrosion Cracking and is a progressive fracture that occurs as result of the combined influence of tensile stress and a corrosive environment.
External Interference	Could be caused by, for example, excavating machinery during construction work, by piling to lay foundations or directional drilling to install other utilities. External interference is often referred to as third party damage, but may include first party damage, where the pipeline is damaged during nearby construction work by the pipeline company.
Ground Movement	Typically geotechnical causes, including earthquakes, landslides, subsidence (including subsidence caused by mining activities), or hydrotechnical, including washout at river crossings.
Hot Tap in Error	Where a connection has been made by error to a high pressure transmission pipeline incorrectly identified as a low pressure distribution pipeline or even as a water pipeline.
Material Failure	During the manufacture of steel, impurities can sometimes remain in the molten steel. These impurities can form defects in the pipe. Cracking can occur at these defects that eventually grow in size over time leading to pipeline failure.
Overpressure	A pipeline that operates above the design pressure is liable to fail due to the strength of the pipe not being able to contain the pressure of the contents.
Pipeline Fitting	Failure of joints and other fittings located on the pipeline.
Other	Including, for example, fatigue, operational error, etc.
Unknown	Cause unknown.

Pipeline Exposure and Incident Data

As discussed above, there are 1,109,461 km.years of pipeline exposure from 2008 to 2015 within the FFA database. Both the cumulative exposure and the annual exposure are shown in Figure 3. A similar graph for the 114 incidents within the FFA database occurring on the pipelines and associated fittings represented by the pipeline exposure stored in the database is given in Figure 4 and is also for 2008 to 2015.

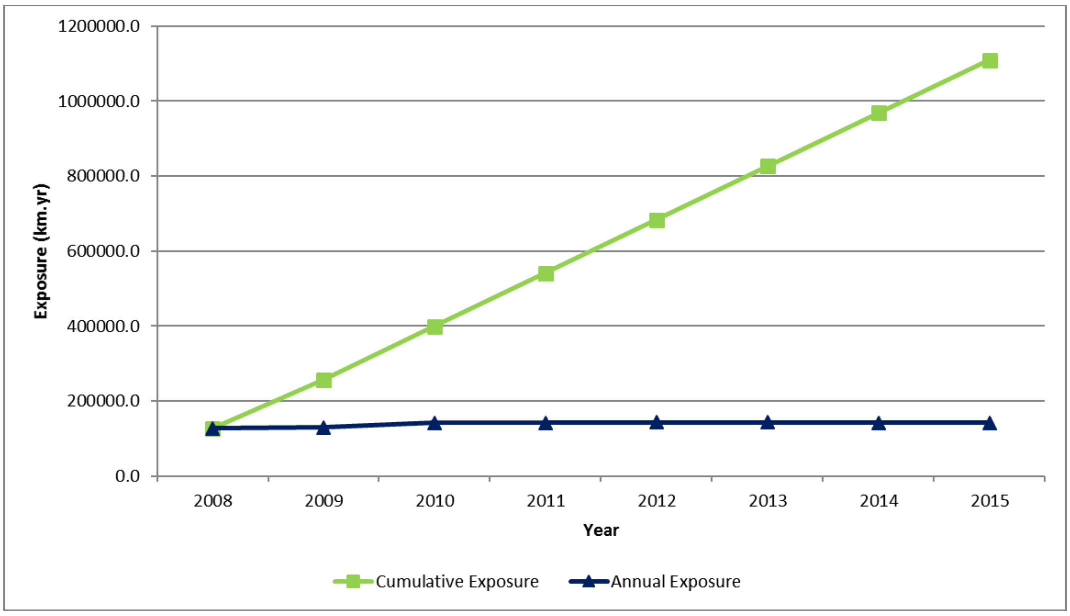


Figure 3: Pipeline exposure within the FFA database from 2008 to 2015

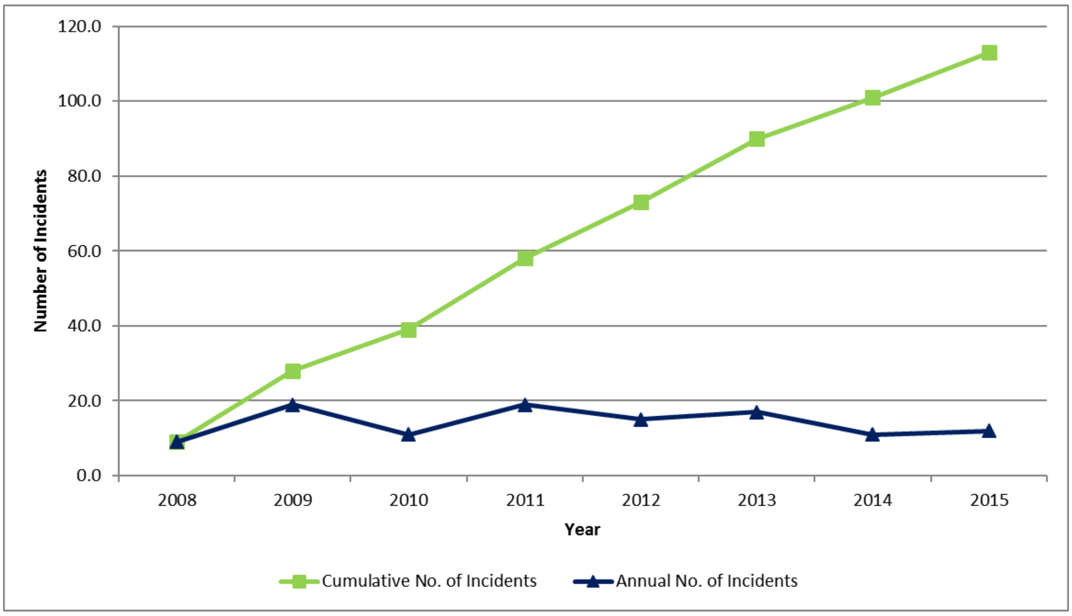


Figure 4: Pipeline incidents within the FFA database from 2008 to 2015

Primary Failure Frequency

The Primary Failure Frequency (PFF) is the total number of incidents divided by the total pipeline exposure within a specified time-period. Table 3 provides a summary of the PFF data for the whole FFA database excluding incidents on fittings and the European data subset from 2008 to 2015. In addition, the latest five year average for the European data subset from 2011 to 2015 is also included in the table for reference.

The five year average for the European data subset from 2009 to 2013 is included in

Table **4** in order to allow direct comparison with the equivalent 5-year averages given in the EGIG and the UKOPA databases.

Table **4** shows there is good agreement between the FFA and the EGIG databases.

Table 3: Primary Failure Frequencies (PFF) for FFA database

From	To	Interval	Number of Incidents	Exposure (km.yr)	PFF (per 1,000 km.yr)	Dataset
2008	2015	8	111	1,109,461	0.100	Complete dataset
2011	2015	5	72	711,000	0.101	Complete data set (5-year average)
2008	2015	8	61	543,635	0.112	European dataset
2011	2015	5	36	357,317	0.101	European data set (5-year average)

Table 4: Comparison of five year averages for FFA, UKOPA and EGIG databases

From	To	Interval	Number of Incidents	Exposure (km.yr)	PFF (per 1,000 km.yr)	Database
2009	2013	5	50	340,950	0.147	European FFA Data
2009	2013	5	110	700,000	0.158	EGIG
2009	2013	5	12	114,480	0.105	UKOPA

Functionality within FFA Database – Independent Parameter Analysis

Existing databases such as UKOPA and EGIG allow the estimation of pipeline failure frequencies from historical data for each parameter independently. The FFA (Failure Frequency Analysis) project is also able to do this; for example, Figure 5 shows the pipeline failure frequencies by diameter class, Figure 6 shows the pipeline failure frequencies by wall thickness and Figure 7 shows the pipeline failure frequencies by failure cause. Thus, companies can use the FFA database to easily produce pipeline and incident data in a format suitable for submission to other pipeline incident databases such as EGIG.

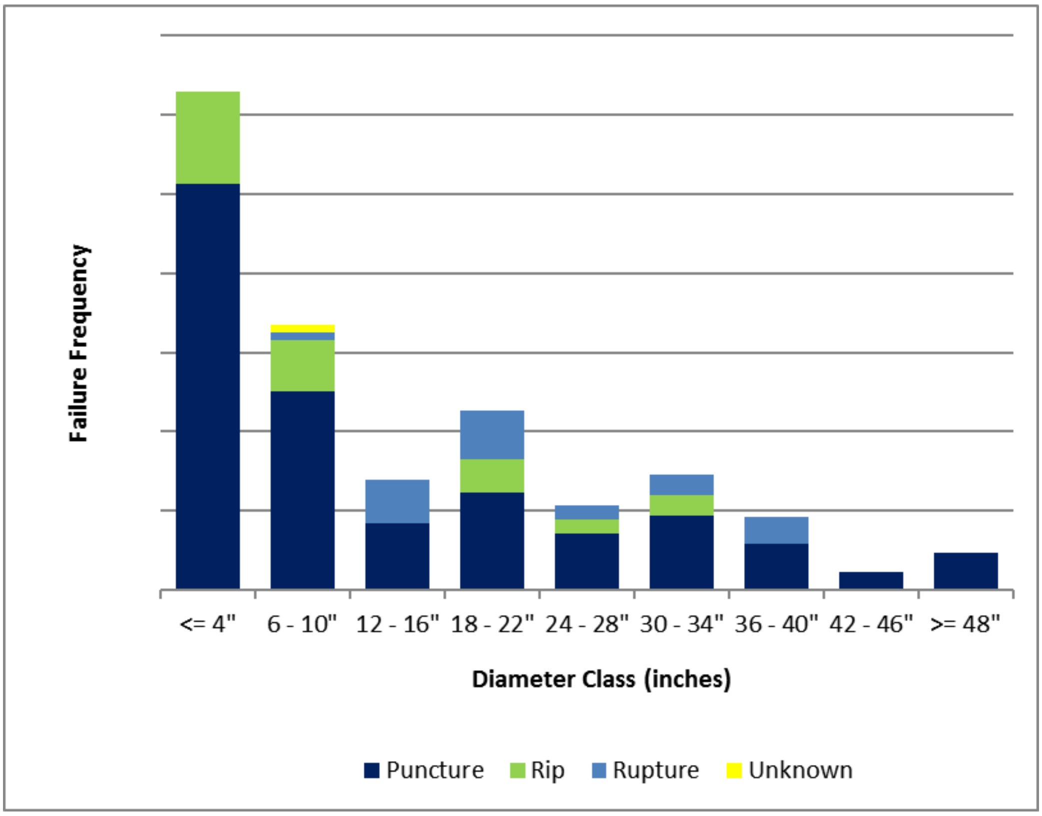


Figure 5: Pipeline failures by diameter class within the FFA database from 2008 to 2015

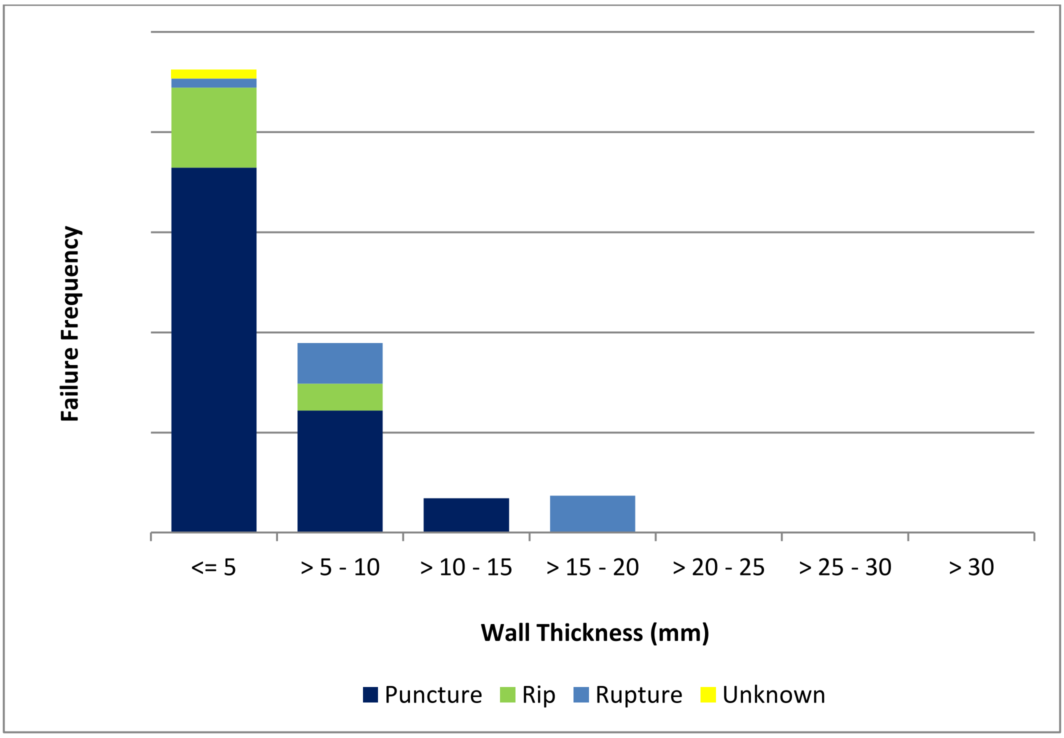


Figure 6: Pipeline failures by wall thickness within the FFA database from 2008 to 2015

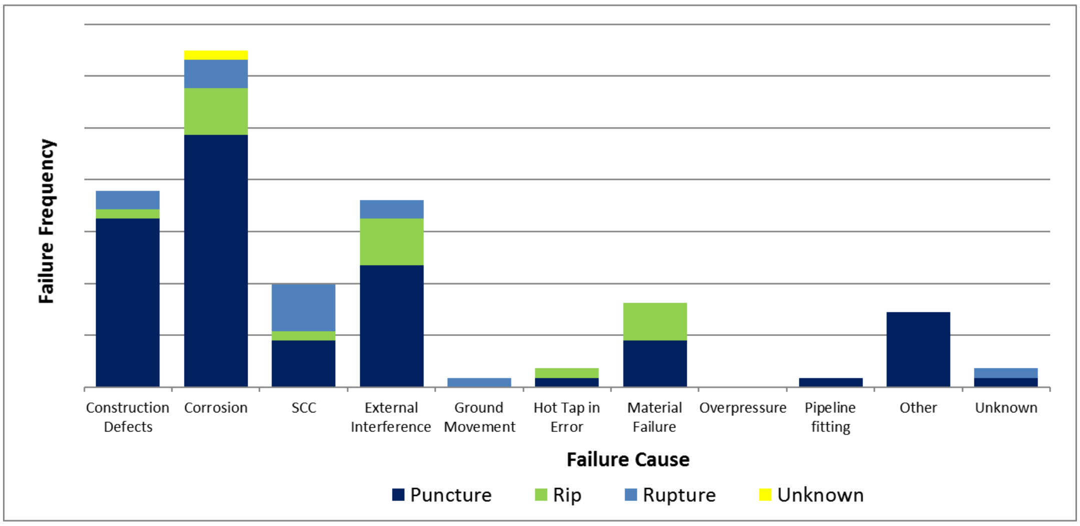
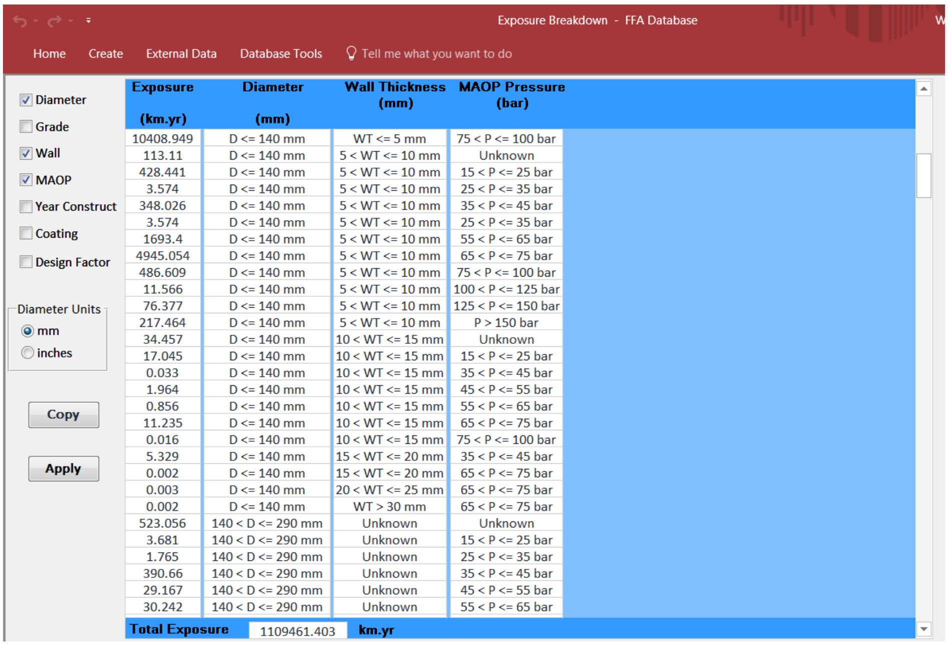


Figure 7: Pipeline failures by failure cause within the FFA database from 2008 to 2015

Figure 5 to Figure 7 demonstrate that the FFA database can present pipeline failure frequencies in the same format as seen in many other databases such as UKOPA and EGIG. So, from Figure 5 it is possible to determine the failure frequency for a given diameter class regardless of wall thickness and from Figure 6 it is possible to determine the failure frequency for a given wall thickness category regardless of diameter. This information can also be obtained from the published UKOPA and EGIG reports. However, the advantage of the FFA database is that it can also be used to break down the failure frequencies into smaller categories with intersecting parameters; for example, Figure 9 illustrates the variation in failure frequency for each wall thickness category within a given diameter class. (Figure 9 uses wider diameter classes than in Figure 5 for illustration purposes; however, it is possible to split the data into the original diameter classes if required.)

Functionality within FFA Database – Multiple Parameter Analysis

The main difference between FFA and the EGIG or UKOPA databases, is the ability of the FFA to use a range of queries that have been developed to enable companies to "slice and dice" the pipeline exposure, number of incidents and failure frequency for combinations of classes. An example query for the pipeline exposure is given in Figure 8.



Exposure (km.yr)	Diameter (mm)	Wall Thickness (mm)	MAOP Pressure (bar)
10408.949	D <= 140 mm	WT <= 5 mm	75 < P <= 100 bar
113.11	D <= 140 mm	5 < WT <= 10 mm	Unknown
428.441	D <= 140 mm	5 < WT <= 10 mm	15 < P <= 25 bar
3.574	D <= 140 mm	5 < WT <= 10 mm	25 < P <= 35 bar
348.026	D <= 140 mm	5 < WT <= 10 mm	35 < P <= 45 bar
3.574	D <= 140 mm	5 < WT <= 10 mm	25 < P <= 35 bar
1693.4	D <= 140 mm	5 < WT <= 10 mm	55 < P <= 65 bar
4945.054	D <= 140 mm	5 < WT <= 10 mm	65 < P <= 75 bar
486.609	D <= 140 mm	5 < WT <= 10 mm	75 < P <= 100 bar
11.566	D <= 140 mm	5 < WT <= 10 mm	100 < P <= 125 bar
76.377	D <= 140 mm	5 < WT <= 10 mm	125 < P <= 150 bar
217.464	D <= 140 mm	5 < WT <= 10 mm	P > 150 bar
34.457	D <= 140 mm	10 < WT <= 15 mm	Unknown
17.045	D <= 140 mm	10 < WT <= 15 mm	15 < P <= 25 bar
0.033	D <= 140 mm	10 < WT <= 15 mm	35 < P <= 45 bar
1.964	D <= 140 mm	10 < WT <= 15 mm	45 < P <= 55 bar
0.856	D <= 140 mm	10 < WT <= 15 mm	55 < P <= 65 bar
11.235	D <= 140 mm	10 < WT <= 15 mm	65 < P <= 75 bar
0.016	D <= 140 mm	10 < WT <= 15 mm	75 < P <= 100 bar
5.329	D <= 140 mm	15 < WT <= 20 mm	35 < P <= 45 bar
0.002	D <= 140 mm	15 < WT <= 20 mm	65 < P <= 75 bar
0.003	D <= 140 mm	20 < WT <= 25 mm	65 < P <= 75 bar
0.002	D <= 140 mm	WT > 30 mm	65 < P <= 75 bar
523.056	140 < D <= 290 mm	Unknown	Unknown
3.681	140 < D <= 290 mm	Unknown	15 < P <= 25 bar
1.765	140 < D <= 290 mm	Unknown	25 < P <= 35 bar
390.66	140 < D <= 290 mm	Unknown	35 < P <= 45 bar
29.167	140 < D <= 290 mm	Unknown	45 < P <= 55 bar
30.242	140 < D <= 290 mm	Unknown	55 < P <= 65 bar
Total Exposure	1109461.403	km.yr	

Figure 8: "Slice and Dice" form for pipeline exposure within the FFA database

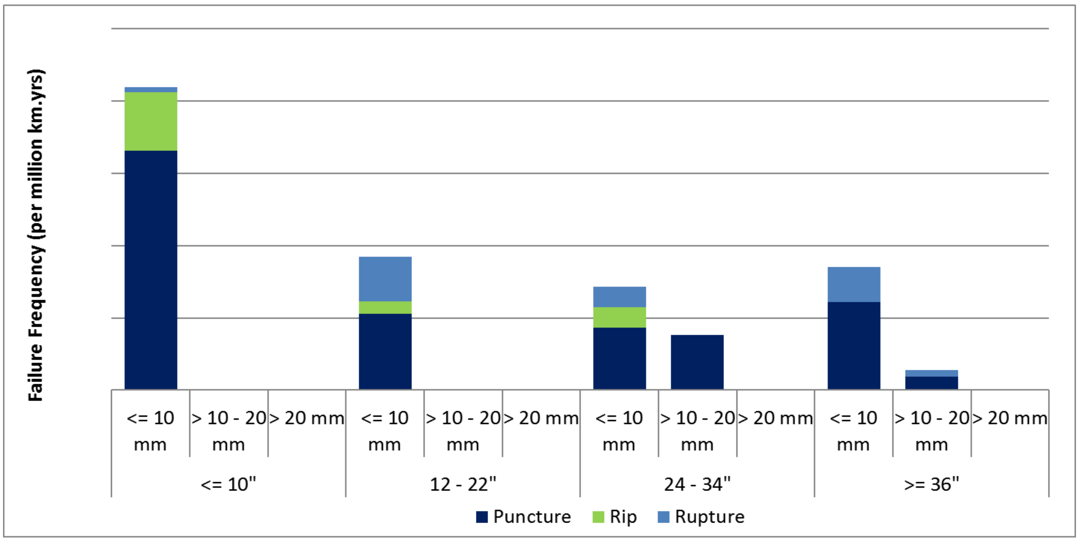


Figure 9: Pipeline failures by diameter and wall thickness within the FFA database from 2008 to 2015

Figure 9 highlights that for smaller diameter pipelines (less than 24"), all failures occurred on pipelines with a wall thickness of 10mm or less whereas for larger diameter pipelines (greater than 24") failures also occurred on pipelines with a wall thickness of 10 to 20mm. Comparison of the frequencies recorded in Figure 9 with the exposure distribution in Figure 10, highlights the correlation between the amount of pipeline within the database for a given wall thickness/diameter combination and the failure frequency. In fact, there is some evidence from comparing these two graphs for the largest diameter class (greater than 36") that thick walled pipelines are inherently safer than thin walled pipelines

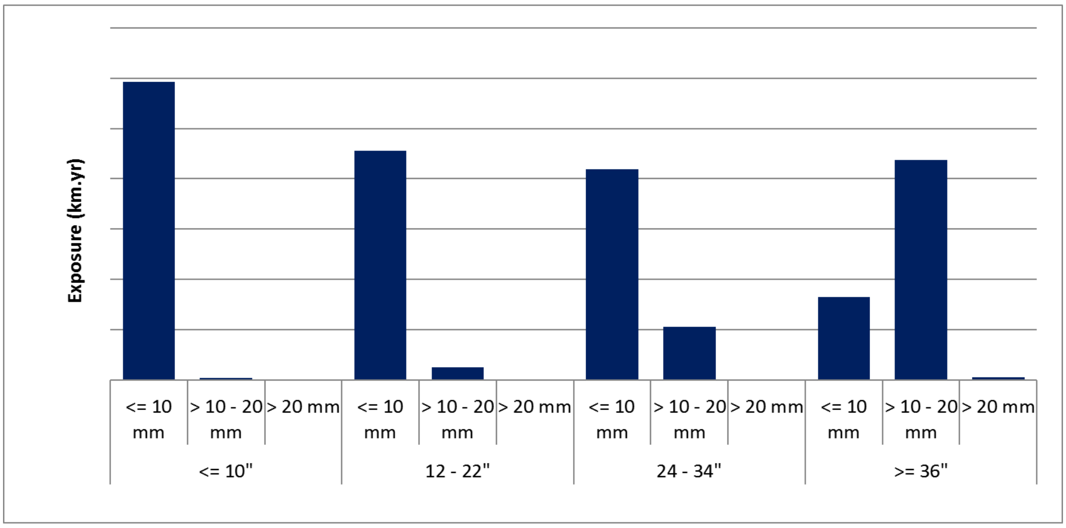


Figure 10: Exposure by diameter and wall thickness within the FFA database from 2008 to 2015

The example above illustrates how the failure frequency can be broken down by diameter and wall thickness for the three different failure modes. It is possible to easily break this failure frequency down with more parameters if required. So, for example, Figure 11 illustrates how the failure frequency can be broken down by Maximum Operating Pressure (MAOP) as well as diameter and wall thickness whilst Figure 12 shows the effect of further dividing the frequencies from Figure 11 by the failure mode.

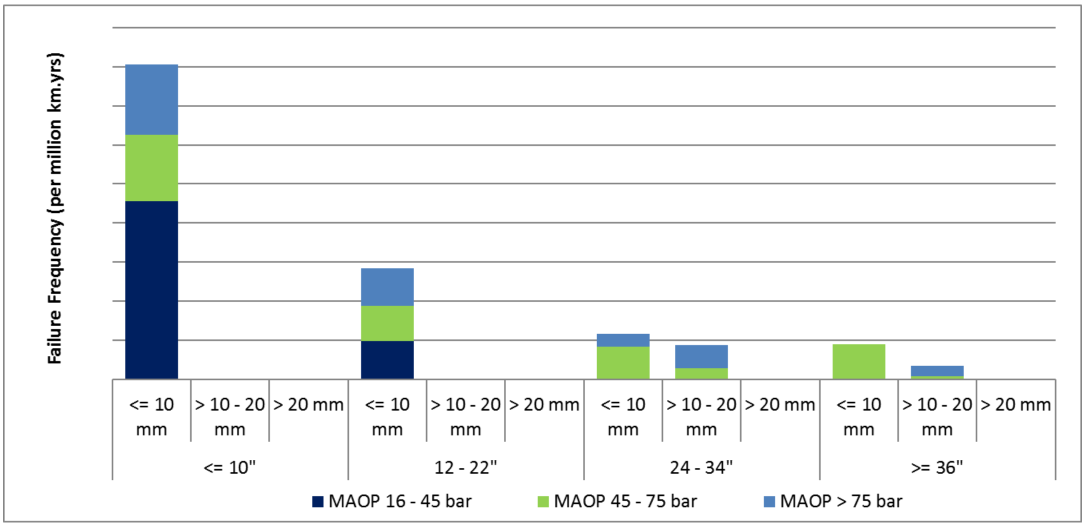


Figure 11: Pipeline failures by pipeline diameter, wall thickness and MAOP within the FFA database from 2008 to 2015

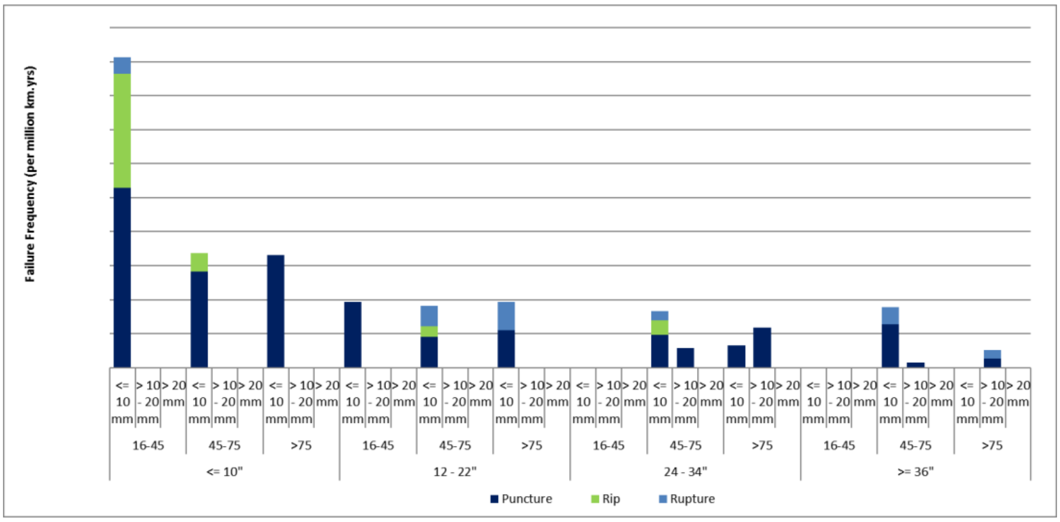


Figure 12: Pipeline failures by pipeline diameter, wall thickness, MAOP and failure mode within the FFA database from 2008 to 2015

Each time the data is sliced and diced into smaller sub-divisions, the number of incidents and corresponding exposure in the category is reduced. This is illustrated in the example in Table 5.

Table 5: Influence of slicing and dicing on failure frequency

Nominal Diameter (inches)	Wall Thickness (mm)	MAOP (bar)	Failure Mode	Number of incidents	Exposure (km.yrs)	Failure Frequency (per million km.yr)
24 – 34”	All	All	All	17	262,202.3	64.8
24 – 34”	≤ 10 mm	All	All	15	209,415.8	71.6
24 – 34”	≤ 10 mm	45 – 75 bar	All	12	144,760.2	82.9
24 – 34”	≤ 10 mm	45 – 75 bar	Puncture	7	144,760.2	48.4

Discussion

There are currently ten contributing companies in the FFA project, operating gas transmission pipelines in the UK, mainland Europe, North America and Asia. The FFA database requires the pipeline population data to be collected in such a way that more accurate pipeline failure frequencies can be determined based on pipeline-specific parameters. Pipeline and incident data is currently stored in the FFA database for years from 2008 up to and including 2015. Although the database is relatively new, because some of the participating companies operate very significant lengths of gas transmission pipelines, the quantity of data in the database has already reached a total exposure over 1 million km-years; sufficient for meaningful high level analysis of the incident data to be performed and the results compared with other databases.

The FFA database captures all gas release incidents associated with onshore buried gas transmission pipelines, including gas releases from pipeline fittings and leaking flanges where these fall outside the fence of an installation. However, the inclusion of failures of pipeline fittings in simple analysis can be misleading, because the pipeline fitting that has failed may have very different properties to the main body of the pipeline with which the data entry is associated (for example, a failure of a small bore tapping on a large diameter, thick wall pipe). At this stage, the database records all of the gas release incidents, but does not include a count of the fittings and flanges connected to the buried pipelines in the database and, hence, it is not possible to calculate a gas release incident frequency for fitting and flanges. Although the number of incidents associated with fittings is small, for the purposes of the illustrations in this paper, these incidents are not included in the examples. As the data in the database grows, it may be an area of future interest to investigate this aspect further; for example, by estimating the number of fittings associated with the pipelines in the database by extrapolation from a small sample where the number of fittings associated with the pipelines is known and, hence, to make an estimate of the gas release frequency per fitting per year.

The FFA database has proved to be extremely powerful in the ways that the data can be analysed and presented, because of the structure of the pipeline population. For example, it is possible to sub-divide the data for a particular combination of pipeline diameter, pressure and wall thickness, rather than only for each parameter independently as is the case for other databases. Whilst the examples in the paper illustrate how powerful the "slice and dice" mechanism within the FFA database is, the results should be treated with caution as it is relatively easy to slice and dice the data so finely that there is only one or no incidents in each category which may give low failure frequencies. Alternatively, the exposure may be reduced to such an extent that a single incident could lead to unrealistically high failure frequencies. Consequently, the statistical significance of such finely sliced data is low and so the absolute failure frequencies are not shown on some of the graphs in this paper, to avoid the values being used inappropriately, until sufficient data has been recorded for such values to be considered robust.

Conclusions

The FFA database has been developed to become a very powerful tool which allows participating companies to make pipeline failure frequency estimates based on historical data, taking into consideration multiple pipeline-specific parameters. The quantity of data in the database has already exceeded 1 million km-years of pipeline exposure in the period 2008 – 2015, sufficient for meaningful high level analysis of the incident data to be performed, and growing steadily to allow the advanced functionality of the database to be utilised on an increasingly extensive dataset.

Acknowledgements

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References

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[2] UKOPA, 2015, Pipeline Product Loss Incidents and Faults Report (1962 to 2014), UKOPA/15/003.