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A probabilistic model for a gas explosion due to leakages in the grey cast iron gas mains

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ABSTRACT

In this paper we propose a model for the probability of an explosion caused by a leakage form grey cast iron pipes in the city of Amsterdam as a function of pipeline and environmental characteristics. The parameters in the model are quantified, with uncertainty, using historical data and structured expert judgment, by use of the Classical Model. Eleven experts from Dutch distribution system operators (DSO) and Kiwa Gas Technology participated in the research. The model has to provide the overall probability of an explosion per year and a prioritization of pipes in terms of their potential contribution to the probability of explosion, which can help DSO's to prioritize their replacements.

1. Introduction

The Netherlands has the largest gas field in Europe and the tenth largest in the world [1]. These gas reserves enable the production of gas for the next 50 years. The Dutch transmission system operator (TSO) and distribution system operators (DSO) transport the natural gas from well to end user. This is done by transporting gas under pressure through pipelines. The total length of the gas infrastructure is approximately 130,000 km and is separated into a transport network and a distribution network.

TSO transports gas regionally in the Netherlands through the transport network, which is operated under a maximum pressure of 40–67 barg (above atmospheric). The transport network is used to supply gas to large industry (including power producers) and the regional gas distribution companies.

DSO distributes gas to Dutch households and smaller industry through the distribution network. Approximately 36,000 km of the distribution network is operated by Liander. The distribution network consists in general of two grids operating at different pressure levels; a high pressure grid and a low pressure grid. The high pressure grid is generally operated under a maximum pressure of 8 barg, although maxima of 1 and 4 barg are also possible. The high pressure grid is used to transport gas to the right district and also to supply gas to smaller industry. In a district station the pressure of the high pressure distribution grid is reduced to the low pressure distribution grid. The pressure in the low pressure distribution grid is operated under an over-pressure of 100 mbarg or 30 mbarg. The low pressure distribution grid transports gas to the households and smaller industry.

Pipelines of the high pressure distribution grid are mainly made of steel or polyethylene (PE). The pipelines of the low pressure grid consist mainly of ductile Polyvinyl chloride (PVC), unplasticised PVC and PE. However, the distribution network of Liander still consists of 10% of grey cast iron pipes.

Grey cast iron is an alloy of iron, graphite (carbon), manganese and silicon, which is used for gas pipelines since the beginning of the 19th century. Grey cast iron is an irregular (heterogeneous) material by nature. This irregularity is caused by the flakes of graphite. As a result of these material properties grey cast iron has extremely high compressive strength, low tensile strength and a poor ductility.

Based on the material properties grey cast iron is a so called brittle material. Brittle materials tend to break if they are subjected

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to a bending stress, whereas other materials (like PE of PVC) deform before they break. Beside sudden rupture due to a bending stress (as a result of its breaking characteristics) grey cast iron pipes are vulnerable for two types of corrosion; pitting (a specific form of corrosion) and graphitization (a process of oxidizing of iron as a result of current resistance and pH value of the soil, from now on called uniform corrosion). Corrosion can accelerate the fracturing process or can be a direct cause of leakage.

Under the right conditions (gas concentration between 5% and 15% of air as well as a spark from an ignition source) gas can explode. Two explosions caused by (sudden) fracture in grey cast iron pipes happened in the Netherlands in the last ten years. There were no casualties and the effects were limited to serious injuries and material damage. The accident in Amsterdam on August 15th 2001 resulted in two heavily injured people. A second explosion in Amsterdam on March 9th 2008 resulted in four slightly injured people and material damage. However, in Great Britain (Larkhall 1999, four fatalities – Dundee 2002, two fatalities) and in France (Dyon 1999, 11 fatalities – Mulhouse 2004, 17 fatalities), there were multiple fatalities caused by an explosion of natural gas released from a fractured cast iron pipe.

Given the potential impact of an explosion in the grey cast iron gas mains we asked ourselves whether it was possible to model the probability of an explosion and to use this model to prioritize the replacement of grey cast iron mains. Therefore, it was, decided to build a quantitative model for the probability of an explosion caused by a leakage form grey cast iron pipes in the city of Amsterdam as a function of pipeline and environmental characteristics. The model has to provide the overall probability of an explosion per year and a prioritization of pipes in terms of their potential contribution to the probability of explosion so that the most dangerous pipes could be replaced first.

The big challenge in building such a model was in combining an available data which is neither complete nor collected in one unified format. The model must be as complex as necessary to satisfy the goals of the project and such that it can be quantified with existing data accompanied by expert judgment input where necessary. In Section 2 we introduce the available data and discuss assumptions concerning model complexity motivated by discoveries observed in the data. Section 3 contains the description of the model and its quantification with data. The quantification of the model has been assisted with expert judgment. We summarize the expert judgment study in Section 4. Section 5 contains model results and presents short sensitivity analysis concerning assumptions made in the model. Finally in the last section conclusions and recommendations are given.

2. Data analysis

The first step of the model building process was to discuss with experts the most important influences leading to gas accident. Liander employees were a valuable source of information in this respect. To extend our knowledge of the problem a literature study has been conducted. We found that the fracture in pipes is the most common cause of leakages and it might occur as a result of ground loading [2] or 3rd party damage [3]. Corrosion is also regarded as one of the main causes of pipeline failures [3,2]. Apart from these mechanisms, Liander experts indicated joint failures as a source of leakages.

Each failure mechanism depends on several characteristics concerning pipes as well as some environmental characteristics. In [7] the list of the characteristics is proposed. They are e.g. pipe diameter, wall thickness, gas pressure but also soil type and pH, water table etc.

To quantify the model we required available sources of data. We had an access to the following database: (1) Geographic Information System (GIS)—diameter, pressure, age, length, location; (2) KwalUGas—inspection results of replaced pipes (for instance environmental characteristics and corrosion); (3) KLIC—announcements of 3rd party activity; and (4) NESTOR—leakages and failures.

Analysis of these data bases allowed us to make decisions concerning assumptions in the model. Our findings are presented next.

2.1. Pipes' characteristics

Pipe characteristics were obtained from the geographical information system (GIS) database. There are 985 km gray cast iron pipes in Amsterdam. The vast majority of pipes (85%) are operated at a pressure of 100 mbarg. The remaining 15% represent pipes that are operated at a pressure of 30 mbarg and 1 barg.

The most frequent in Amsterdam are pipes with diameter 150 mm. They constitute 40.4% of the whole population of grey cast iron gas pipelines. Less popular are pipes with the diameter 100, 200, 250, 300, 400 and 500 mm. Together they make up about 50% of grey cast iron pipes in Amsterdam. Remaining pipes with diameters 80, 125, 450, 600, 750, 800 and 900 mm are rare and they add up to 10% of the population.

Fig. 1 shows the histogram of the age distribution of gray cast iron pipes in Amsterdam. Most of the pipes are 30 to 60 years old. This is due to discovery of gas fields in 1959 in Groningen which led to rapid development of gas mains.

The wall thickness was not reported in the GIS database. Thus we calculated the wall thickness as a linear function of the diameter (dm) using formulas introduced in [4]. For pipes with pressure 30 and 100 mbarg the wall thickness is as follows:

$$wt = \frac{11}{12}(7 + 0.02dm)$$

The relationship between wall thickness and diameter for pipes with pressure equal to 1 barg is:

$$wt = 7 + 0.02dm$$

According to the above formulas a 30 mbarg pipe with diameter 80 mm have the wall thickness equal to 7.88 mm. The thickest walls of 25 mm have 1 barg pipes with 900 mm diameter. The most popular pipes, i.e. those with 150 mm diameter and 100 mbarg pressure have 9.17 mm wall thickness.

We found various lengths of pipes ranging from 20 cm to 680 m in the GIS database. The mean length of gray cast iron pipes in Amsterdam is 21.25 m but the distribution is skewed towards shorter lengths.

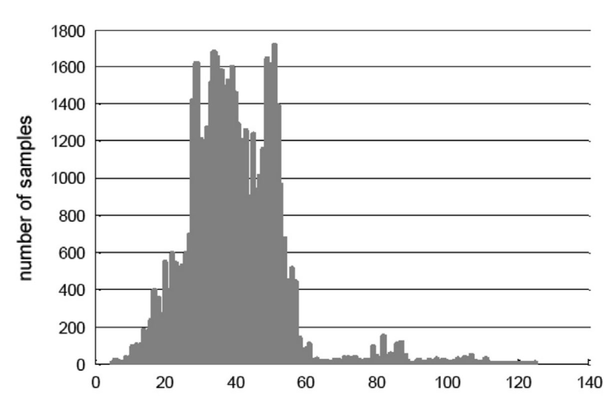

Fig. 1. Histogram of the distribution of age (in years) of grey cast iron pipes in Amsterdam.