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Assessing the consequences of pipeline accidents to support land-use planning

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ABSTRACT

With the rapid development of industry, the number of pipelines that are proposed or under construction is increasing year by year, connecting different regions of a country and, more and more, different countries. Thus, an accidental loss of containment from a pipeline involves a certain risk, which could imply potential consequences on people, equipment and environment. Therefore, the existence in some places of a large net of pipelines has a clear influence on land-use planning, especially in the ones with intense activities, which usually are the inhabited zones. In this paper, a historical analysis is performed on a sample of 1063 accidents that occurred in onshore pipelines, to illustrate the risk associated to these systems and its significance in land-use planning.

1. Introduction

The characteristics of the present highly complex and interconnected societies require a continuous flow of materials and energy from one geographical area to another. In particular huge amounts of often hazardous materials, mainly liquids or gases, are transported from production/extraction sites, through processing plants, to the final consumption areas.

The transportation can be performed by different modes: road, rail, ship (sea/river) or pipeline. Most of these modes have a strong interaction with the landscape, as often the transport takes place over long distances, crossing both rural and urban areas.

One of the most used modes in the case of fluids is the transport through pipelines, which is usually considered one of the safest among the aforementioned ones, as discussed in Section 2. Nevertheless, most of the transported fluids are flammable or toxic. Thus, an accidental loss of containment from a pipeline involves a certain risk, which could imply potential consequences on people, equipment and environment. These consequences will depend on the amount and properties of the released material, and on the features of the affected zone (rural or urban). Taking into account the large length of pipelines in many countries, with the consequent interaction with the land, and the huge amount of materials transported every day, the occurrence of an accident cannot be neglected. In fact, accidents or incidents following the release from a pipeline have actually occurred with a certain frequency, and some of them with severe consequences.

In some places, the existence of a large net of pipelines has therefore a clear influence on land-use planning, especially in the zones with intense industrial activities, which usually are also the most inhabited ones. Concerning this scenario, two possible situations can be found: (a) the existence of a pipeline in a zone initially not inhabited, which becomes urban later on, and (b) the existence of a pipeline in an already existing urban zone. In both cases, the risk inherent to a possible loss of containment increases as compared to that in a rural zone, due to the activities associated to the human presence. However, even in uninhabited regions an accident can have serious consequences on the environment, polluting soil or water or damaging areas of special ecological interest.

These are complex situations. Land-use planning aims to protecting human health and the environment through the definition of safety zones around the pipeline. It contributes also to reducing the risk of third part activities -especially excavation works- by applying different measures; these can include technical measures such as increasing pipe wall thickness or burial depth or marking the pipeline corridor, or organizational ones as, for example, ensuring that any excavation work will be communicated before starting (COWI, 2011).

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It is nowadays widely recognized the significance of historical analysis of past accidents as a source of valuable information on their main aspects (types, frequency, causes, etc.). In this paper such a historical survey is performed on a set of 1063 accidents that have occurred in onshore pipelines, with a statistical analysis of their main features.

2. Worldwide networks for onshore pipelines: a relatively safe alternative

Pipeline transport of liquids and gases is an important sector of the oil and gas industry and, more generally, process industry. After World War II the construction of pipelines experienced a huge increase, connecting different regions of a country and, more and more, different countries. Among the longest pipeline systems we can cite the Natural Gas Transmission System in Russia, with diameters up to 1422 mm and 170.7 thousand kilometers in length (GAZPROM, 2015), and the Trans-Alaska Pipeline System, transporting crude oil, with a diameter of 1219 mm and a length of 1300 km (APSC, 2013).

The length of pipelines is continuously increasing. As an example, Fig. 1 shows the variation of the total length of the European gas transmission pipelines system in EGIG (2015); a steady growth can be observed during the last forty-three years.

When transporting a hazardous fluid, pipelines are a relatively safe system as compared to other transportation modes. Although millions of kilometers of pipelines are installed, the frequency of fatal accidents is relatively low (Papadakis, 1999; Buonvicini et al., 2015). Comparing the diverse transportation possibilities, Boot (2013) emphasized the following points:

– Rail/road/ship are batch modes, while pipeline is a continuous one.
– Batch systems imply loading/unloading activities, which involve a significant contribution of human factor. When all major accidents (both in fixed plants and in transportation) are analyzed, it is found that 8–10% have occurred during loading/unloading (Vílchez et al., 1995).
– In batch transportation, the failure frequency includes the probability of the truck/railcar/ship being present. The pipeline has a 100% presence factor.

Boot (2013) presented a comparative analysis on the transportation of 100,000 t/year of propane by the different transport modes, based on the associated quantitative risk analysis. The required number of transports for rail, road and ship modes was taken into account, and a diameter of 65 mm was considered for the pipeline. The results showed that the pipeline mode was more dangerous than the other modes when accidents with reduced consequences were taken into consideration, but it was significantly safer for more severe accidents, being as an average less dangerous than the other modes.

Another comparative study was performed by the Transportation Research Board (TRB, 2004), taking into account the rate of fatalities and injuries per ton-mile. The result showed that pipeline transport was overall the safest system (only tank-ship and barge were safer in terms of injuries per ton-mile).

However, even though these analyses show that pipeline transport is a relatively safe system, it is a fact that, due to the large number of pipelines on many countries, accidents occur with consequences on people and environment. An example of a very severe one is that occurred in Ghislenghien, Belgium in 2004 (ARIA, 2009). An excavation machine damaged a pipeline transporting natural gas; a few weeks later, an increase in the pressure caused the explosion of the pipe. A large jet fire appeared immediately and large pipe fragments were ejected. 23 persons were killed and 132 were injured. Another case, with severe consequences on environment, was the one occurred in Marsall (Michigan) in 2010, when a pipeline transporting a heavy crude oil broke and a spill of 4200 m^3 polluted the Kalamazoo River.

It is thus believed that an accurate historical analysis of a sample of accidents as large as possible can give interesting and useful information on their modalities and consequences, allowing to identify appropriate preventive measures.

3. Accident types

Following the release of a hazardous material from a pipeline, the accidental sequence can follow diverse paths according to the released material properties (flammability, toxicity and volatility), the pipeline situation (underground or surface), the release characteristics (full bore rupture, a hole, etc.), the meteorological conditions and the environmental circumstances (urban, rural). The event tree in Fig. 2 shows a simplified scheme of the diverse possibilities.

An important aspect is whether the pipe is aerial or buried. If it is aerial and the fluid is flammable, there is the possibility - especially in a zone with human activity- of immediate ignition. In this case there will be a jet fire if the released material is a gas, or more probably a pool fire (even though a jet fire could also occur) if it is a liquid. If there is no ignition, the product, if liquid, will pollute the soil and potentially the aquifers -there is also the possibility of being drained towards a torrent or a creek- or it will disperse into the atmosphere if it is a gas or a volatile liquid. If the material is flammable, there is still the possibility of delayed ignition; in this case, there can be a flash fire or a vapor cloud explosion and, afterwards, a pool fire (liquid) or a jet fire (gas).

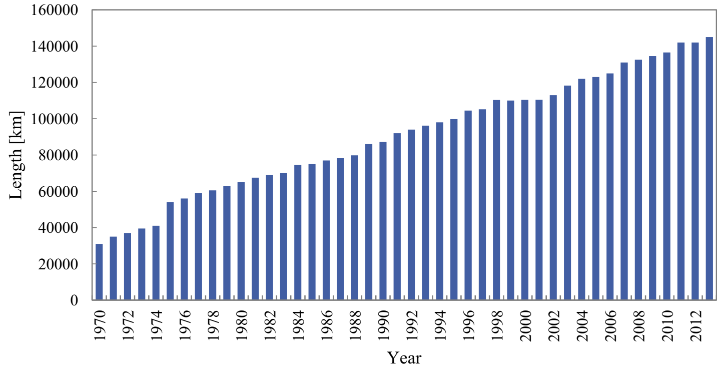

Fig. 1. Total length of the European gas transmission system in EGIG (EGIG, 2015).

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