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INVITED PERSPECTIVES

CHAPTER OVERVIEW

This chapter includes a number of essays providing invited perspectives from recognized thought leaders in the international pipeline industry. These essays are intended to be thought provoking and impart some element of wisdom from seasoned practitioners. The essays include:

Section 13.1 Title, author

Section 13.2 Title, author

Section 13.3 Title, author

Section 13.4 Title, author

Section 13.5 Title, author

Section 13.6 Title, author

THIS CHAPTER FOCUSES ON:

1. ***What are emerging trends in the pipeline world?***
2. ***What are the challenges facing the industry?***
3. ***How do we advance the state-of-the art?***

PIPELINE RISK ASSESSMENT - A NEW ERA

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BIOGRAPHY

W. Kent Muhlbauer is an internationally recognized authority on pipeline risk management. In this field, he is an author, lecturer, consultant, and software developer. Techniques developed by Mr. Muhlbauer are in use by the largest pipeline operators in the U.S. and in pipeline operations in many other countries. Mr. Muhlbauer is an advisor to private industry, government agencies, and academia, as well as a frequently invited speaker at industry conferences worldwide. Mr. Muhlbauer also has an extensive background in pipeline design, operations, and maintenance, having held multiple technical and management positions in a pipeline operating company for many years prior to founding WKM Consultancy, LLC, a company providing specialized consulting on pipeline issues.

ABSTRACT

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INTRODUCTION

Earth movements are one of multiple threats to a pipeline system's integrity (see Fig 1). The term 'geohazards' is often used to encompass all types of potentially damaging earth movements, from landslides, erosion, subsidence, and seismic activity to buoyancy, scour, and seabed instability. Each of these phenomena warrants treatment in a pipeline risk assessment for a pipeline system.

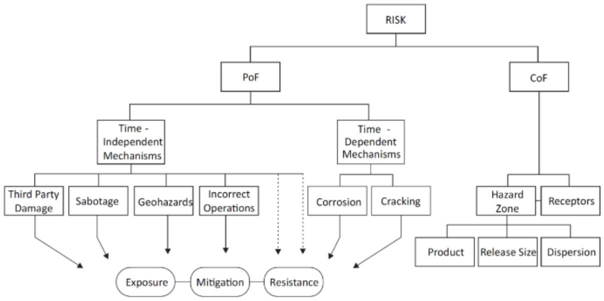

Figure 1: Framework for modeling of pipeline risk (from Muhlbauer 2015)

Several key players have been involved in managing pipeline geohazard risks. The geotechnical scientist/engineer has been perfecting his craft; getting better and better at understanding and forecasting geohazard events that could damage pipeline components. The pipeline designers continue to improve structural engineering models to better design components to withstand new forces. Risk assessment specialists have improved the way in which risk can be quantified while, spill/release specialists have continued to refine their models that detail consequence potential

However, until recently, there has been a bit of a gap in putting all the pieces together from these varied specialists into a single, comprehensive framework to truly understand pipeline geohazard risk. This essay reports on the key breakthrough that now allows the work of these disciplines to combine into a powerful risk assessment.

GEOHAZARDS

There are many good books written on geohazard risk. Nonetheless, even the well-tested methods discussed in current texts can benefit from a recent breakthrough in quantifying risk. That breakthrough is the realization that, just as in the design phase of engineered systems, a risk assessment has to independently measure three things in order to gain a complete understanding of PoF.

The comparison to the design process goes like this: we know that "Mother Nature hates things she didn't create". So, its best to acknowledge that our new, engineered installation will be under constant attack (corrosion, land movements, outside forces, fatigue, etc). There are two basic ways we can respond to this attack and prevent failure. We can defend against the attacks or we can make our system so strong that it can absorb the the damage from the attacks without failing. For practical reasons, designs typically use both.

The interplay between these three elements—what is attacking; how effective are the defenses; what happens if the attack reaches the component—is the key to measuring

PoF. We must understand the contribution from each in order to really understand PoF.

Armed with good PoF estimates, we can couple them with CoF estimates and arrive at much more meaningful and useful risk estimates. Each location along a pipeline can have a $/year Expected Loss (EL) value assigned from each potential threat. Imagine the improvements in risk management that are possible once risks are fully understood and quantified in this way.

MEASURING POF

All plausible failure mechanisms must be included in the assessment of PoF. Each failure mechanism must have each of the following three aspects measured or estimated in verifiable and commonly used measurement units:

- Exposure (attack)—the type and unmitigated aggressiveness of every force or process that may precipitate failure
- Mitigation (defense)—the type and effectiveness of every mitigation measure designed to block or reduce an exposure
- Resistance—a measure or estimate of the ability to absorb damage without failure, once damage is occuring

Measuring exposure independently generates knowledge of the 'area of opportunity' or the aggressiveness of the attacking mechanism. Then, the separate estimate of mitigation effectiveness shows how much of that exposure should be prevented from reaching the component being assessed. Finally, the resistance estimate shows how often the component will failure, if contact with the exposure occurs. In risk management, where decision-makers contemplate possible additional mitigation measures, additional resistance, or even a re-location of the component (often the only way to change the exposure), this knowledge of the three key factors will be critical.

Units of measurement are transparent and intuitive. In one common application of the exposure, mitigation, resistance triad, units are as follows. Each exposure is measured in units of 'events per time and distance', ie events/mile-year, events/km-year, etc.

An exposure event is an occurrence that, in the absence of mitigation and resistance, will result in a failure. To estimate exposure, we envision the component completely unprotected and highly vulnerable to failure (think 'tin can' wall thickness). So, almost any kind of earth movement involving a pipeline is an event.

Mitigation and Resistance are each measured in units of % representing 'fraction of damage or failure scenarios avoided'. A mitigation effectiveness of 90% means that 9 out of the next 10 exposures will not result in damage. Resistance of 60% means that 40% of the next damage scenarios will result in failure, 60% will not.

For assessing PoF from time-independent failure mechanisms—those that appear random and do not worsen over time—the top level equation can be as simple as:

PoF = exposure x (1 – mitigation) x (1 – resistance)

With the above example units of measurement, PoF values emerge in intuitive and common units of 'events per time and distance', ie events/mile-year, events/km-year, etc.

As an example of applying this to failure potential from landslides, let's assume that the following inputs are identified for a hypothetical pipeline segment:

- Exposure (unmitigated) is estimated to be 0.2 rainfall-initiated landslide events per mile-year, ie, an event every 5 years.
- Using a mitigation effectiveness analysis, SME's estimate that 1 in 10 of these exposures (attacks) will not be successfully kept away from the pipeline by the existing mitigation measures. In other words, an overall mitigation effectiveness of 90%.
- Of the exposures that reach the pipe, despite mitigations, SME's perform an analysis to estimate that 1 in 4 will result in failure, not just damage. This estimate includes the possible presence of weaknesses due to threat interaction and/or manufacturing and construction issues. So, the pipeline in this area is judged to be 75% resistive to failure from this these landslide events, once contact occurs.

These inputs combine for a simple PoF[1] calculation:

> (0.2 landslide events per mile-year) x (1 – 90% mitigated) x (1 – 75% resisted) = 0.005 failures per mile-year from landslides

This suggests a landslide-related failure about every 200 years

This is a very important estimate. It provides context for decision-makers. When subsequently coupled with consequence potential, it paints a valuable picture of this aspect of risk.

Note that a useful intermediate calculation, probability of damage (but not failure), also emerges from this assessment:

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[1] More correctly, a FoF, frequency of failure

(0.2 landslide events per mile-year) x (1 – 90% mitigated) = 0.02 damage events/mile-year

This suggests landslide-related damage occurring about once every 50 years.

This damage estimate can be verified by future inspections such as in-line inspection (ILI). Differences between the actual and the estimate can be explored: eg, if the estimate was too high, was the exposure overestimated, mitigation underestimated, or both? This is a valuable learning opportunity.

GEOHAZARD EXPOSURES

An interesting aspect of geohazard as an exposure–an ‘attack on’–pipeline integrity, is the distinction between measuring the geohazard event vs measuring its effect on a pipeline. For example, the initiating geohazard event could be ‘flood’, resulting in subsequent events of

- scour,
- bank erosion,
- avulsion,
- debris transport,
- and others.

We often have published recurrence intervals for these initiating events and/or the secondary events. These published frequencies are the first step in our estimates of the PoF attack frequency. However, distinct from the initiating geohazard event, the events for which we really seek an estimate of attack frequency are the pipeline’s integrity threatening events. The pipeline-threatening events to be related to the above list of geohazard events are

- lack of support (increasing the gravity loading)
- buoyancy (creating an uplift force)
- lateral loadings (from flowing current and debris)
- oscillations (fatigue loadings)

These will be some fraction of the geohazard event frequencies since not every geohazard event will generate sufficient forces to threaten the pipeline.

GEOHAZARD MITIGATION

Much geohazard risk reduction occurs in the design phase. Realtime mitigation is often not a prime method to reduce PoF but nonetheless an available option at times. Stress relieving, rockslide barriers, dewatering, bank stabilization measures, concrete coating, anchoring systems are examples of mitigation against geohazard threats. While some might argue that these, rather than being barriers--blocking the exposure—some of these are actually modifying the exposure frequency. Bank stabilization, for instance, is not actually a barrier but rather a pre-emptive action. Nonetheless, in the interest of transparency, it seems more useful to include as a mitigation anything that either blocks or reduces an exposure.

GEOHAZARD RESISTANCE

The ability of a structure (pipeline component, in this case) to resist an external force of any kind is fairly well understood, although it is not a trivial estimation process. The estimation is further complicated by the potential presence of defects in the structure, reducing its ability to resist a load. Examples include dents, gouges, corrosion, ovalities, cracks, and others. We can employ a range of analyses rigor, from simple informed-estimation to finite element analyses using sophisticated calculation routines.

For initial stage risk assessments, we should at least use methods that reasonably approximate the actual ability of the structure to absorb damages in light of all that is known or reasonably inferred about the component. This can be done in a broadcast-fashion, where a few strength-approximating routines are efficiently applied to hundreds of miles of pipeline via database algorithms.

GEOHAZARD COF

A more detailed risk assessment could pair each failure mechanism with a corresponding set of consequence scenarios. A simpler assessment will often use a single CoF estimation routine to link to all possible failure mechanisms, as illustrated in Fig 1.

A challenge in pipeline geohazard risk analyses is the need for primary, secondary, etc, consequence evaluation. As previously noted, the initiating geohazard event may not generate the most consequences. It is often the potential subsequent events that hold the majority of consequent potential.

For instance, the risk of dam failure does not always include a quantification of all related damages that may unfold for days, weeks, or longer after the actual failure. While the geohazard expert can determine the height, flowrate, an duration of released flood waters and the ensuing channel damages, he is rarely the expert on population escape potential, property values, clean up costs, long term environmental and societal ramifications, etc, all of which are legitimately a part of the dam failure.

Similarly, ignition potential from a pipeline release, hazard zone generation, thermal radiation levels, service interruption costs, and many others, are not typically in the geohazard expert’s realm of expertise.

Fortunately, the risk assessment framework now available to practitioners provides clear placeholders for each discipline’s experts to provide input. That collective of expertise makes the entire risk assessment more accurate and defensible.

GEOHAZARD EL

Finally, the modern risk assessment framework provides for the monetization of risks—a measurement unit with a powerful common denominator.

Risk expressed in this fashion is called "expected loss" (EL). It encompasses the classical definition of risk: probability x consequences, but expresses risk as a probability of various potential consequences over time.

An EL analysis captures the high-consequence-extremely-improbable scenarios; the low-consequence-higher-probability scenarios, and all variations between. It does this without overstating the influence of either end of the range of possibilities, resulting in a fair representation of risk and providing powerful risk management decision-support.

KEY TAKE-AWAYS

The improvements in risk assessment—including the ability to efficiently quantify geohazard PoF—have opened new doors in managing risks. Armed with a modern risk assessment, risk **management** becomes much more transparent and even exciting. Seeing actual risk levels and generating cost/benefit analyses of proposed risk reduction actions provides clarity and, often, some 'ah-ha!' moments.

REFERENCES

www.pipelinerisk.net

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