development of reinforcement corrosion. When operation time reaches the design useful life of 100 years, the failure probability increases to 0.01537, which is a so small value that means a relative safety state for this investigated tunnel and no maintenance measure need to be adopted.

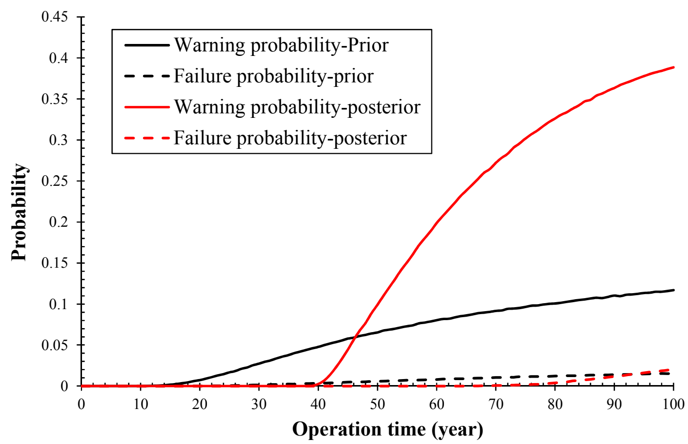


**Figure 6. The reliability of shield tunnel**

After Bayesian updating, the waring and failure probabilities all increase slowly over time. The failure probabilities is always higher than the waring probabilities. When operation time reaches the design useful life of 100 years, the waring probability increases to 0.38853, the failure probability increases to 0.002081(as shown in Tab.3). It is seen that the posterior model prediction values are always larger than the prior model prediction values because of the conservative assumptions of some parameters in the initial stage, such as well environment and material parameters. Meanwhile, the result after Bayesian updating is more consistent with the monitoring data. As for failure state, the failure probabilities before and after Bayesian updating are fairly small in the design useful life of 100 years.

**Table 3. The failure probability of shield tunnel under operation year**

| Operation time (year) | Fifty | One hundred |
|---|---|---|
| Warning probability | Prior：0.06537<br>Posterior：0.09901 | Prior：0.11690<br>Posterior：0.38853 |
| Failure probability | Prior：0.00578<br>Posterior：<10e-5 | Prior：0.01537<br>Posterior：0.02081 |

## CONCLUSION

This paper analyze the reliability of shield tunnel using Bayesian method, the several conclusions are drawn based on the proposed study:

(1) A probabilistic prediction model of cross-section deformation is established considering the bending stiffness degradation caused by reinforcement corrosion to evaluate the long-term reliability of shield tunnel .Markov chain Monte Carlo simulation is used to update the parameters with monitoring information. The probability distributions of the parameters in the probabilistic model can be any types of distributions.

(2) After Bayesian updating, the mean value of the predicted cross-section deformation after one hundred years of operation is 130.57 mm and its standard deviation is 66.43 mm. The warning and failure probabilities all increase over time .When the service time reach the design useful life of 100 years, the failure probability is about 0.020881.

(3) The comparison between the theoretical and the observed data validates the proposed methodology, which can efficiently improve prediction accuracy, reduce prediction uncertainty and ultimately get more reasonable assessment conclusion. More data in the future can also be used to update the model prediction using Bayesian MCMC in order to obtain more reliable results of the tunnel safety evaluation.

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# Case Study: Excavation Adjacent to High Pressure Natural Gas Transmission Pipelines—A Risk Management Approach

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**Abstract**

This paper presents a case study of the risk assessment and management process conducted on an industrial project which involved the design and construction of a 35 ft. (10.6 m) tall and 1100 ft. (335.2 m) long soil/rock-nailed retaining wall in close proximity to two in-service high pressure natural gas transmission pipelines.

The design and construction of the retaining wall required excavation, rock blasting and soil/rock nailing in close proximity to the active pipelines. This contributed to project risks far beyond the typical geotechnical construction risk profile. In addition to the obvious safety risks, additional economic loss exposure was evident as damage to the pipelines and resulting impacts from a service outage could have resulted in regional economic harm.

A holistic and integrated 5 step risk management process was a critical element of the contractor's acceptance of this unusual risk as the project was being evaluated for bid and execution. This case study addresses the risks identified and the risk management tools used to address them, with a particular focus in the use of insurance as a risk transfer mechanism.

## INTRODUCTION

This paper presents an overview of the risk assessment and management process conducted on a large industrial project which required blasting, extensive excavation, and wall construction in close proximity to two in-service, high-pressure natural gas transmission pipelines. Site space constraints required excavation of soil and rock to a depth of 35 ft. (10.6 m) at a distance of only 30 ft. (9.1 m) from the nearest of the parallel gas pipelines, which were buried only 3 ft. (0.9m) below the ground surface (minimum cover). A permanent soil/rock nail wall, 1100 ft. (335.2 m) long, was constructed directly on the boundary of the right-of-way for these adjacent pipelines. The excavation and related retaining wall required:

- Blasting of rock as close as 50 ft. (15.2 m) from the pipelines
- Mechanical rock splitting and excavation as close as 30 ft. (9.1 m) from the pipelines
- Drilling and installing soil nails, the top 2 rows of which passed directly below the closest pipeline
- Support of the pipeline right of way and future construction equipment operating in the right of way without any significant movement of the pipelines

Construction adjacent to these pipelines generated unusual geotechnical risk exposures which impacted the project's risk profile. A stepwise risk management process is described herein, which was used to identify, assess, and mitigate the geotechnical risk exposures, with particular focus on the use of insurance as a risk mitigant. (See Witt, et al. (1993) for more background on such a 5-step risk management process). This paper also addresses how insurance professionals consider geotechnical risks in the context of an overall project of this nature.

This paper is intended as a companion to a paper by Newhouse, et. al. (2017), entitled "Blasting, Drilling Soil Nails, and Excavating Adjacent to Natural Gas Transmission Pipelines - Risk Assessment and Design/Construction Approach - Case History", which is being presented in Track A of this conference.

## STEP ONE - PROJECT RISK IDENTIFICATION

The project described herein consisted of a new industrial plant which was located on a greenfield site zoned for industrial use within a rapidly-growing, suburban area. The closest residential neighborhood and commercial property was less than two miles away. Two 30-inch (0.8 m), in-service high-pressure natural gas pipelines ran through the site at shallow depth with about 3 ft. (0.9 m) of cover soil. Site constraints required that excavation directly adjacent to the pipeline right-of-way (ROW) to a depth of 35 ft. (10.6 m), and for a length of 1100 ft. (335.2 m), would be needed to develop the facility. A permanent vertical cut face would be required only 30 ft. (9.1 m) from, and parallel to, the nearest of the two pipelines.

Site investigation indicated that this excavation would encounter competent bedrock beneath a broken, weathered rock zone and soil overburden. The upper materials would require permanent support on the vertical face of the excavation, but blasting would be needed to complete the excavation of the deeper, competent bedrock. Furthermore, the excavation support system was required to support potential future pipeline construction equipment within the adjacent ROW. A soil-nail wall with shotcrete facing was chosen to support the excavation face. The soil nail wall, at a distance of 30 ft. (9.1 m) from the nearest pipeline, was constructed with nails 35 ft. (10.6 m) long. The uppermost nails passed within 7 to 9 ft. (2.1 to 2.7 m) beneath the pipelines, as illustrated in the following conceptual cross section (Figure 1). For additional details, see Newhouse, et. al. (2017).

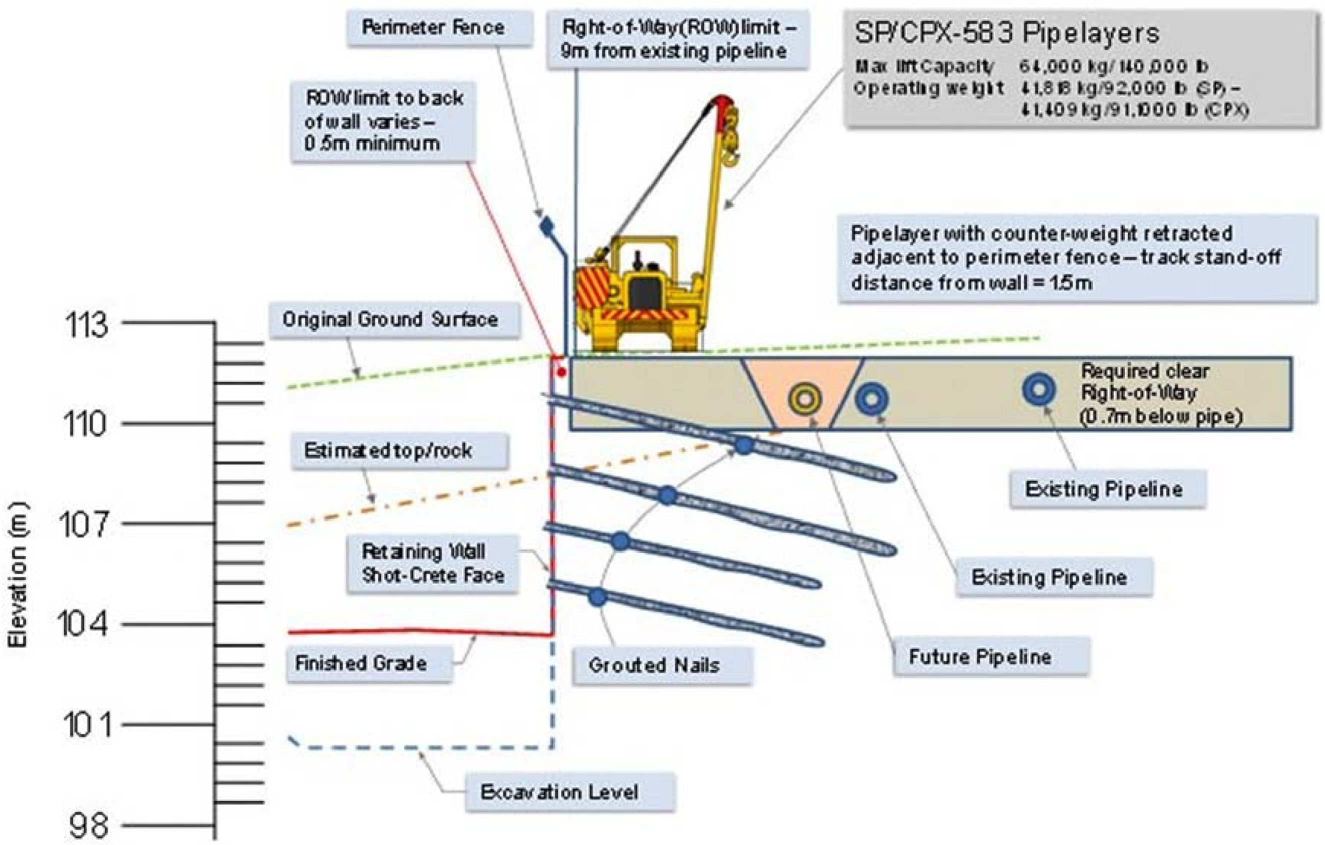


**Figure 1. Industrial Project. Soil Nailed Wall - Conceptual Cross Section (in metric units)**

Prior to the design and construction of this project, the engineering/procurement/construction (EPC) contractor undertook an assessment to identify the geotechnical risks specifically associated with blasting, excavation, and nail-wall installation adjacent to the pipelines. According to Guerra & Teixeira, while there are risks that are common to virtually all construction projects, such as, damage to persons or property, defective work, negligence, natural catastrophes, vandalism, terrorism, insolvency of contractors/subcontractors, change orders, among others (ICE, 2016), the pipeline-related risks represented unusual risk exposure that potentially required non-standard assessment and mitigation strategies.

Damage to one or both gas transmission pipelines either during or after construction constitutes the fundamental pipeline-related risk, but this might be caused by several different design and construction risks, which warrant closer scrutiny. Design of the soil-nail wall might be faulty, or the actual subsurface conditions on which that design was based might differ from the conditions assumed during design. Blasting damage, rock excavation overbreakage, nail installation errors, or loss of pipeline support through ground movements constitute construction risks, as does the damage that might be caused by construction equipment crossing the buried pipelines from one side of the site to the other.

## STEP TWO - PROJECT RISK MEASUREMENT/ASSESSMENT

Risk measurement or assessment considers both the frequency of the risk event and the severity of the incident. Damage to gas transmission pipelines does not occur frequently so the frequency or likelihood of causing construction project damage to transmission pipelines is typically considered to be relatively small, if for no other reason than much construction occurs at a significant distance from transmission pipelines. However, damage from excavation accounts for 14% of all transmission pipeline failures (PHMSA, 2011). Clearly, blasting, rock excavation, and soil nail installation in close proximity to the pipelines represented a qualitatively larger likelihood of pipeline failure on this project than is considered typical, although insufficient data was available to quantify this greater likelihood. Hence, significant attention and analysis in the planning and execution of the work was considered essential.

The results of a transmission pipeline failure can be very severe. The severity of such events stems from both the potential of injury to individuals at the site and/or adjacent to the event, as well as the potential direct costs of repairing the damage to the pipeline itself as well as to adjacent property (e.g. construction equipment, the plant equipment) which may have also been damaged. For this project, pipeline damage could also have directly impacted a critically important construction and commissioning schedule, resulting in further direct costs. The combined direct costs may be estimated on a site-specific basis, but data on reported pipeline incidents may also be used to assess the potential severity of such events. For example, during the period from 2006 to 2014, 26 pipeline damage incidents resulted in one death and $91 million in direct property damage for one particular pipeline owner (WDRB, 2014). Third party liability damages resulting from a 2010 pipeline explosion in San Bruno, California totaled $565 million. Commercial considerations preclude the authors of this paper from publishing project specific estimated costs.

On the other hand, the potential indirect costs of pipeline damage, such as those born by businesses and other gas users who depend on the continued delivery of gas to conduct their operations, might be staggering and may be extremely difficult to estimate.

Because the likelihood of pipeline damage was deemed to be greater than normal, and because the potential outcomes of a pipeline damage incident were potentially very severe, the EPC contractor considered the resulting risk exposure to be significant prior to undertaking the industrial plant project. A similar assessment was performed for a variety of other project risks, and the results were combined into a risk register which assigns a risk rank identifying which project risks required risk mitigating strategies. Figure 2 is an example of a risk matrix used in a risk assessment. The cell color denotes the severity band of the risk to assist in the decision making as to which risks to treat and the priority order in which they are to be managed. As noted above, commercial considerations preclude the authors from publishing project specific ratings within this risk matrix.

The risk mitigation strategy relating to pipeline damage is described in the next section

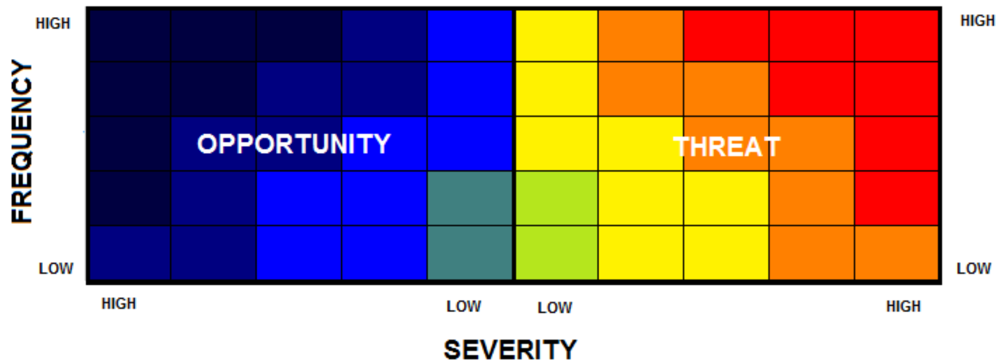


**Figure 2. Risk Matrix – Levels of Risk**

## STEP THREE - PROJECT RISK MITIGATION

Project risk mitigation may take many forms, as illustrated in Figure 3. Risk Avoidance pertains to the elimination of a chance of a loss to occur (declining work). Risk Assumption, pertains to the retention or acceptance of the threat or opportunity using a threshold as a baseline. Risk Reduction consists of lowering the probability that the risk will occur. Risk Transfer pertains to the management and control of risks by shifting and allocating the risk of loss to another party through a contract (contractual risk transfer) or through a third party (e.g. an insurance company).

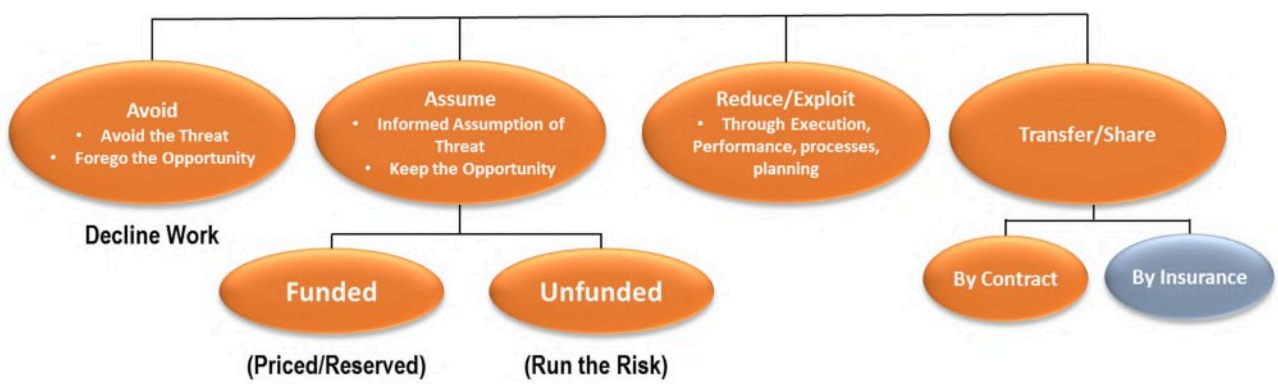


**Figure 3. Project Risk Mitigation Strategies**

The EPC contractor chose a combination of risk reduction and risk transfer measures to mitigate the pipeline damage risk exposure on this project.

**3.1 Risk Reduction Measures.** The EPC contractor undertook a number of proactive design and construction measures to reduce the likelihood of pipeline damage. Design measures included retention of a specialized design professional experienced in the design and construction of soil nail walls, careful probing and surveying of pipeline locations, detailed layout and positioning of soil nails to avoid the confirmed pipeline locations, design for a range of possible subsurface conditions, design of the soil nail wall for equipment surcharge throughout the pipeline ROW, and design for safe crossing of the pipelines by construction during the plant construction. Construction measures included retention of a specialized blasting subcontractor experienced in similar pipeline proximity blasting, imposition of the pipeline owners' blast standoff distance and vibration limitations with appropriate vibration monitoring at the pipeline(s), tightly spaced drilling at the excavation face to minimize overbreakage of rock, careful soil nail positioning and tight tolerances on their drilling, gas company representatives present during all activities within or adjacent to the pipeline ROW, strict no-work buffer zones, and highly-qualified full-time geotechnical construction monitoring. For additional details, see Newhouse, et al. (2017).

**3.2 Risk Transfer Measures.** Under the contract with the Owner, the contractor for this project was responsible for the design and construction activities. The contractor, then subcontracted the design and construction of the retaining wall, the blasting, and the excavation work. Thus, there was no direct contractual relationship between the Owner and the subcontractors for this critical work.

The EPC contract and subcontract agreements contained appropriate indemnification and hold harmless clauses, which allowed for the shifting of liabilities among the parties involved in the respective contracts. Industry best practice is to shift the liability to the party that is in the best position to control the exposure. For example, errors and omission in the design of the soil nail wall could be best controlled by the design engineer for the wall. Stability of the excavation and its effect to nearby in-service gas pipelines during construction could be best controlled by the earthwork subcontractor. Broad indemnity agreements, which attempt to shift liability for one's party sole negligence to the other party in the contract, are prohibited in most states by anti-indemnity statutes. However, more equitable indemnity agreements which define the mutual sharing of liability based on a party's contribution to the loss and based on who is best positioned to control the loss exposure, are commonly included and acceptable under these statutes. Clauses of this nature were included in the EPC contract and in the subcontracts for the project described herein.

In the event of a catastrophic loss (e.g. pipeline explosion), the contractual indemnification clauses will define the extent of obligations of each party to pay for losses (e.g. personnel injury or death, fire caused by natural gas leak, damage to industry plant) resulting from damage to underground gas lines during construction. The most likely third party claimant would be the owners of the gas lines for damage to their property, including potential resultant economic loss caused by construction operations. Additional risk transfer was accommodated through the acquisition of appropriate insurance for this risk exposure. The most common types of insurance required are property and liability insurance. Of most interest for the pipeline related risk exposure, is Commercial General Liability (CGL) and Umbrella/Excess Liability Insurances.

Commercial General Liability (CGL) insurance and Umbrella/Excess Liability Insurances, will provide protection for legal liability for alleged property damage and/or personal injury, including accompanying economic loss from the aforementioned potential third party claimant – the utility owner, including property owners, nearby affected business, project owner, and other contractors, members of the public and governmental entities. For this particular case, limits of Commercial General Liability (CGL) insurance procured were higher than what would be typical limit requirements for this type of work, including a high deductible. Typically, a percentage of these insurance requirements are passed down to the subcontractors which would respond as a first level of protection before contractor's coverage is triggered. It is also important to recognize that anti-indemnity statutes do not prevent parties to the contract from shifting liability arising out of their sole negligence through insurance. Therefore, careful review of contract language insurance requirements by both a lawyer and insurance risk manager should be conducted to avoid adding unnecessary project risk costs by inadvertently providing insurance that exceeds the degree of the indemnity obligation assumed.

For losses caused to property and commercial owners not directly affected by a catastrophic loss, but whose businesses have been interrupted downstream along the pipeline, the indemnity between them and the utility owner will define the extent of damages for which the utility owner will be responsible. However, careful consideration should be given to indemnities between the EPC contractor and the utility owner where financial penalties associated with the utility's obligation to deliver service may be shifted to the EPC contractor if the damage to the pipeline were to occur.

Limitation of liability (LOL) clauses represent another risk transfer mechanism by attempting to limit the extent of liability of one or more parties in a contract for losses resulting from, among other things, negligence and breach of contract terms. A common example LOL clause in design contracts limits design liability to the fee received for design services or to some prescribed limit. These transfer mechanisms may not be fully effective because the LOL clauses are only applicable to the agreement between the two contractual parties and are not applicable with respect to third parties with whom no contract exists. Nevertheless, to effectively mitigate the pipeline related risk exposure (in addition to declining or renegotiating the design contractor's LOL clause), such as that resulting from a defect in the design of the soil nailed retaining wall during construction (e.g. economic loss, personnel injury, damage to industrial plant and damage to pipeline), additional limits of professional liability insurance were required from subcontractors.

This effectively transfers some of the risk to additional insurance underwriters while allowing the contracting party to negotiate an equitable distribution of the added insurance costs.

**Risk Transfer of Geotechnical Risks – An Insurance Industry View**. Geotechnical risks are considered to be a high hazard class of business to underwrite in the insurance marketplace. This view is driven by the severity of the losses insurers have experienced over the years relative to economic loss, bodily injury and property damage on projects. Losses in this class tend of be