GEO-RISKS IN THE BUSINESS ENVIRONMENT

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ABSTRACT: Companies are exposed to many geo-risks that arise from work done on engineering projects. Companies are also exposed to other geo-risks that are not specifically related to performance on a project. This paper considers risks that may arise from the characterization of the subsurface conditions and how engineers conceptualize and model these conditions and related uncertainties. The author considers one of the areas of greatest exposure to companies is incorrectly defining the mode(s) of deformation or failure (the conceptual model). In addition, significant risks may arise by doing calculations using models that have not been checked and verified or when the user does not understand the algorithms and model boundary conditions. Business risks can arise from large, long-term projects that may be greater than those on smaller, more limited assignments because of the expanded conditions within the scope of work. Business risks can also arise from events that are rare, have extreme impacts, and are unpredictable or extremely difficult to predict. Some risks associated with changing legal interpretations are noted and risks associated with working in different states, countries and from different offices are discussed. The limitations and business risks for companies that have project opportunities in OFAC counties is also discussed.

INTRODUCTION

Companies today are exposed to business risks that arise from work in the geotechnical, mining, and geo-environmental areas (business geo-risks) that may be different and more over-arching than risk issues normally associated with a specific project or task. Also, the business risks that can arise on large, long-term projects may be greater than those a company would normally be exposed to on a short-term assignment which has a more limited scope of work. There are also business risks that may arise from rare, extreme impact events that cannot be predicted and can only be evaluated retrospectively. This paper will consider some of the origins of the above three types of geo-risks, and offer some examples of how each type of risk might arise. In addition, some other risks and liabilities associated with the business of consulting will be discussed.

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SITE CHARACTERIZATION, MODE OF FAILURE, AND ANALYTICAL TOOLS

In the past quarter of a century, the development of analytical tools and computing capability has been awesome. Today, engineers are able to analyze problems that could not have been analyzed, in detail, 25 years ago. For example, a transient unsaturated groundwater flow problem can be characterized using a nonlinear partial differential equation. Today this problem can be solved using commercial numerical codes on a computer. The solution to this problem would have been impractical before the development of computer models. In the past, much simpler approximations would have been used and engineers would have bracketed expected outcomes.

The advanced field data collection techniques available today enable professionals to acquire gigabytes of detailed geotechnical and environmental data. The ability to portray the variability of parameters within a geologic stratum or unit is easier and more detailed today than was possible a few decades ago. This variability in the data is often described through the use of probabilistic distributions. In theory, therefore, the current data acquisition and overall design practice should be much better than in the past because of the ability of design professionals to characterize the subsurface conditions more accurately and analyze complex problems more rigorously.

Unfortunately, however, the improved data acquisition methods and more sophisticated analytical techniques do not automatically result in a better conceptual formulation or understanding of the subsurface system, and may not result in better designs. The design professionals must understand the geomorphic history at a site and define the relevant stratagraphic units. Depending on the variability of parameters within a stratum, it may be appropriate to subdivide a stratum into layers or zones having similar parameters. There may be a need for this subdivision for one class of problems and not for another. For example, the subsurface model used, and the associated data needs, may be different for a contaminant hydrogeological assessment than might be needed for a slope stability assessment.

An important, and sometimes overlooked, element to characterizing subsurface is recognizing that it is generally not possible to know what the actual variability is with respect to stratigraphy or design parameters. Subsurface conditions and parameter variability may differ across space and time and may be significantly different than assumed or inferred from limited data; therefore, significant errors may be introduced into the models and analyses. Failing to recognize this uncertainty in models can create business risks related to the geo-practice. Therefore, it is critically important to recognize that uncertainty exists and account for it in reviewing the output from the analytical solutions.

After developing an accurate subsurface site characterization model, a careful assessment must be made of the possible modes of deformation or failure. When considering various mode(s), professionals must assess the kinematic possibility of the material deforming or failing in the manner assumed. Once the most probable mode(s) of deformation or failure is defined, then the professionals must decide how that mode of deformation or failure should be analyzed. An inaccurate definition of the mode(s) of deformation or failure is one of the major business risks that a company may be exposed to in the geotechnical or geo-environmental field. No matter how sophisticated the analysis, if the wrong mode of deformation, failure, or contaminant transport is analyzed, the results will mislead the professionals.

Detailed modeling and analyses should be done only after: 1) the best characterization of the subsurface is defined from an assessment of the geology, material types, and variability of material parameters, 2) the most realistic mode(s) of deformation or failure are determined, and 3) the most appropriate analytical techniques are selected. The fundamental aspects of the profession have not changed as a result of the development of computers and advanced analytical solutions.

Forty years ago (pre-computer and the dawn of digital calculators) when considering a geotechnical project, engineers and geologists developed their best characterization of the subsurface conditions and evaluated what the most realistic modes of deformation or failure might be. Engineers considered whether the mode(s) of deformation or failure were kinematically possible and realistic. If conditions warranted, a stratum might be subdivided into several layers and different parameters assigned to each layer. The design professionals developed their best estimate of the geotechnical parameters that would be used in their analyses for each stratum or layer. Judgment was used in the selection of design parameters; the parameters might not be the mean value of the test data for each layer. This approach was necessary because all the calculations were done by hand, were laborious, and were time consuming to perform. Based on thought and experience, the professionals developed a "sense" or "feel" for how the system would perform and what the expected results might be. Analyses were done to refine or verify the expected results. When computer software was developed to do limit equilibrium slope stability analyses using a method of slices analysis, many consulting firms would insist that the critical failure surface predicted using the computer model be redone manually so the designers could verify the computer output and gain an appreciation for the interaction of the forces and moments.

Where has all the insight and thought gone? In the author's opinion, geotechnical and environmental professionals today sometimes begin running the computer models without having carefully considered: 1) the geologic site characterization (i.e. the site conceptual model), 2) the most realistic mode(s) of deformation or failure, and 3) the applicable design parameters for each unit in the subsurface model. Professionals sometimes rush into initial modeling to "see what is happening" or to "find the answer," but the expected outcomes may not have been carefully considered

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or estimated beforehand. As a result, design professionals may be misled by spreadsheet output or results from commercial computer programs.

Because of the ease of running computer analyses using a range of parameters for each stratum (e.g. the stratum variability), professionals may not consider characterizing a stratum using smaller substrata where the variability of the data within each substrata is smaller. Such an approach might be more realistic in determining where the critical failure surface might be located. Similarly, in environmental projects, subdividing a stratum into different layers, where the layers have different parameters (e.g. hydraulic conductivity), might be more realistic in assessing the movement of groundwater or transport of contaminants within the subsurface.

It is not unusual for professionals to tabulate and manage data on spreadsheets and then perform important analyses or calculations using this data in the same spreadsheet or workbook. New spreadsheets or workbooks are often created for each project or new assignment. It is not uncommon for work on these spreadsheets to be done without documenting on each worksheet the title of what is being calculated, a job number, a date, a file name, a tab name, or a record of the author of the work. In addition, many, if not most, of these *ad hoc* spreadsheets are not checked to ensure the calculations are done accurately for the assumed model or reviewed to ensure the proper parameters were input and implemented properly in the spreadsheet. Yet the results from these spreadsheets are often used as a basis for design and are included in engineering reports. Although it is easy to do data manipulation and reasonably sophisticated calculations with spreadsheet programs, unless the data entry and formulas are checked and verified, professionals can be misled by the results and a company can incur significant liability risks, in the form of negligence claims, by improperly using these tools.

Even when the conceptual model is reasonable, it is still possible to be misled by inappropriate application of the computer model. If the design professional doesn't fully understand the algorithms, understand how to use the computer code, and understand how to properly address the boundary conditions, the computer output may not yield results that are meaningful or realistic. The author considers that unless the professional has a sense of what the computer results should be, it may be difficult for the design professional to assess whether the computer results are reasonable. Independent rough, simple predictions of what the expected answer should be need to be done if at all possible. Improper computer modeling is another area of risk exposure for businesses. These risks may be in the form of negligence claims against the firm and, in some states, against the design professional personally.

There is a growing interest in the use of probability theory to represent model uncertainty and the distribution of possible parameter values in a given zone or at a specific point. This is nominally intended to represent the confidence in the model and the parameter values. This uncertainty reflects the professional's ignorance in what the real conditions are and is different from the variability or fluctuations (e.g.

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in parameter values within a given stratum or layer) with time and space. If done correctly, the probabilistic representation of the model and input parameters can convey the professional's level of confidence in the analysis and model results. It can help the designers highlight which models and parameters have the greatest impact on a design, and by better defining the model and values of the parameters, the confidence in a design can be increased or a more cost effective design developed. However, like any analytical approach, uncertainty theory can be a mixed blessing. If improperly implemented, a probabilistic representation of the data in a layer may obscure a weak zone that can have a dominant impact on the failure mode or mask the impact a strong zone may have on performance.

The author is aware of analyses where data from different geologic formations that had different material parameters and variability were characterized as a single material. It was noted that the spatial variability could be reduced by gathering additional information, but there was no discussion of geomorphic history and material types in the analysis of the data. Advanced probabilistic analyses were improperly applied to the data as if it were from one unit. Such an approach should not be used to characterize different materials as a single unit whose parameters exhibited considerable variability. Just because it is possible to mathematically analyze a broad, diverse, data set does not mean such an analysis should be done if the engineering fundamentals do not support such an analysis.

Consider a case history where the primary consolidation in a thick layer of soft clay was calculated under a large embankment. The primary settlement predictions were conveyed to the owner. The owner, therefore, had an expectation of the magnitude of embankment settlement that would occur. The embankment settled more than double the predicted amount, and the settlement was asymmetric. Settlement plates were used to measure vertical settlement at various locations and slope inclinometers were used to detect lateral deformations in the soft clay. Substantial lateral deformation occurred in the soft clay due to undrained shear deformation. Although the instrumentation was specified by the design professional, no predictions were made of the anticipated time–settlement or time-lateral deformation behavior for the instrumentation. This is an example where the professional's conceptual deformation model was incomplete; since no predictions were made for the time response of each instrument, it was more difficult for the designers to recognize that the performance deviated substantially from their expectation until much later in the project. This example demonstrates the need for the professional to understand all the possible modes of deformation or failure and assess the possibility for each mode to occur. As stated earlier, not understanding and recognizing all the modes of deformation or failure is one of the largest risks that a company may have in terms of business geo-risks.

In another case history, a dam and reservoir system was upgraded by removing a saddle dike in the reservoir and constructing a fuse plug in the area to increase the ability of the reservoir to pass a larger design storm than the dam was originally designed to accommodate. Prematurely, the fuse plug was pressed into service and breached as it was intended to do. What was unexpected was the erosion of the fuse plug outlet channel and the release of much more water from the reservoir than was anticipated. As a result, extensive downstream property and consequential damages occurred. Fortunately, there was no loss of life. This project is another example where all the potential failure modes were not adequately identified or considered at the design stage.

In summary, a company can incur significant business geo-risks on geotechnical, mining, and geo-environmental projects. Some of the areas, which if not done correctly, create these risks:

1) Incorrect development of the conceptual subsurface model
2) Incorrect or incomplete definition of the mode(s) of deformation or failure
3) Incorrect numerical modeling, including:
   a) Selecting analytical techniques that do not comport the mode(s) of deformation or failure
   b) Missing or not recognizing important details in the conceptual model and site data
   c) Incorrectly using computer models
   d) Using spreadsheets that have not been checked or undergone a thorough quality assurance review

The author considers that the sophisticated analytical tools available to designers today should not be used as a substitute for sound, prudent, engineering and geologic judgment. Reliance on modeling results, without thoughtful consideration of the geologic site characterization, appropriate design parameters, and expected outcomes, can create significant liabilities to a company in the form of negligence claims.

RISKS ON LARGE, LONG-TERM PROJECTS

Large, long-term, complex projects may create unforeseen liability issues for companies. Most companies are thrilled to win large, multi-year projects that can keep many dozens or hundreds of employees busy for years or decades. However, budget constraints, schedule issues, along with managerial, cultural, and political issues can influence design details and limit the extent of necessary critical and periodic technical reviews. During the evolution of these projects, the scope often changes and key professionals may retire or be rotated onto other project assignments. As a result, legacy issues and entrenched design logic may prevent a critical examination of all facets of a project design. The logic may have been sound in the past, but may not be appropriate for the current scope of work. Consider the following projects:

- 1984, Union Carbide pesticide plant in Bhopal, India, experienced a leak of methyl isocyanate gas (MIC). Water entered a tank of MIC and caused an exothermic reaction. In June 2010 several ex-employees were convicted of causing death by negligence.

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- 1986, Chernobyl nuclear plant in the Ukraine failed during an unauthorized systems test. Automatic reactor shutdown systems were disabled and a test was run to see how long the turbines could run cooling water pumps without power.
- 1986, NASA Challenger exploded 73 seconds after takeoff. Failure was attributed to an "O" ring on a solid fuel rocket booster.
- 2010, BP Deepwater Horizon drilling platform in the Gulf of Mexico. Design operational decisions associated with completing the well led to its explosion.

The failures of all the above major projects were preventable. The projects had under gone detailed reviews, and complex monitoring systems were in place, but the unthinkable happened. There are also examples of large project failures in civil and mining projects. These projects may not have the same visibility as the above projects but the fundamentals of design, monitoring, maintenance, and project management are similar. Examples of these include:

- 1972, Buffalo Creek dam failure in West Virginia – a 40 to 60 foot high dam retaining coal mine waste failed after a period of heavy rain on February 26. The water level was reported to be near the crest of the dam. The failure resulted in the death of 125 people.
- 1976, Teton Dam in Idaho failed on June 5. The dam was designed by the US Bureau of Reclamation. The most probable cause of failure was a combination of collapse of permeable loess in the core, piping, and a fractured foundation under the dam. The failure resulted in the death of 11 people.
- 1977, Kelly Barnes Dam in Georgia failed on November 6, after several days of heavy rainfall. The original dam was constructed in 1899 and was modified and expanded in 1939. Overall, the dam was reported to be in poor condition and lacked a sufficient design. No specific cause of failure was identified but it included slope failure of the dam and the possible collapse of the low level spillway.

Companies can employ many strategies to help ensure that these large, long-term, complicated projects function effectively. Some of these include:

- Have a crystal clear approach to design, reviews, monitoring, and re-design.
- The design team and management must understand the design requirements and schedule.
- Avoid "group think." Direct reports do not like to deliver bad news to senior managers/leaders. As a result, leaders tend to get overly filtered reports. Effective leaders ask for and demand to hear the bad news.
- Stamp out complacency. All monitoring data must be analyzed as though it is the first set of monitoring results received. Monitoring data should be compared to the predicted response.
- Legacy issues have no place in the project team. A critical assessment must be done and redone to ensure that the current strategy and design approach is the best available at the time.

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- Put in place an effective Review Board. This Review Board must have access to and review basic data, design assumptions, performance criteria, monitoring data, and have an independent look at the approach being used in the conduct of the project. For long-term projects, rotate members of the Review Board to help ensure that new ideas and a fresh look are being provided.

Companies pursuing large, long-term projects should recognize that the legal risks on these projects may be different and more complex than normally experienced on smaller, short-term assignments. As a result, different approaches must be used on the larger jobs. Although the default standard of care for firms working on these large projects is a negligence standard, the circumstances and conditions of the engagement normally implies the need for comprehensive technical reviews, enhanced QC/QA procedures, and other issues to help ensure the work product will function as intended. Careful attention to contract terms is critical on these large projects and the company must continually work to ensure that the expectations of all the parties are aligned throughout the project.

RARE, EXTREME IMPACT, EVENTS

Companies are also exposed to rare, extreme impact events in the course of business or on individual projects. In the book, *Black Swan* (Taleb, 2007), the author discusses what these rare, extreme events (Black Swans) are, and why they are not predictable in advance. These rare and extreme impact events can create major liabilities, and they may create significant, game changing opportunities. Taleb uses the example that if a Stone Age thinker was asked to develop a strategic plan for the future and did not envision the invention of the wheel, his forecast would be wrong. If you were preparing strategic forecasts in the 1970s and 1980s and did not anticipate the evolution of computers, email, and the internet, your estimates would have been incorrect. One of the purposes of a formal risk assessment is to try to identify rare events that might occur that would have serious consequences. Because of the low likelihood of occurrence, these events are often “screened out” in making project decisions. Professionals doing risks assessments must try to identify and evaluate the rare events, but it is not possible to identify the “Black Swans” as defined by Taleb.

Rare and extreme impact events can occur on engineering projects and in the business environment. Two simple examples are provided below that illustrate these “black swan” events.

The Ka Loko Dam in Kauai, Hawaii was constructed in the late 1880s on one side of an existing volcanic cone. The dam had a homogeneous section and had a maximum height of about 40 feet. An overflow spillway was constructed in the right abutment in about 1912 when the dam was raised. The Ka Loko reservoir provided water for irrigation of sugar cane fields in the area. By the early 1970s, the

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commercial production of sugar cane ceased and the reservoir was no longer needed for commercial sugar cane production. Portions of the dam and reservoir were sold or transferred to private owners in the late 1980s.

Following about six weeks of heavy rain, on March 14, 2006, the Ka Loko Dam failed and water rushed downstream, over the Kuhio Highway, and in the process killed seven people. Figure 1 shows a view of the breach in the Ka Loko Dam from the rear of the reservoir taken in May 2006. Figure 2 shows the breach as seen from the right abutment.

Figure 1 - Breach from rear of the reservoir

Figure 2 - Breach as seen from the right abutment

In 1998, the then current owner of the dam had the overflow spillway filled with earthfill so the reservoir water level could be raised. The original location of the spillway was in the right abutment just to the right of the breach shown in Figure 1. After functioning for almost 120 years, the dam failed eight years after the overflow spillway was filled and made non-functional.

The author considers that filling in the spillway over 110 years after construction could not have been predicted and could not have been contemplated by the original designers. The original designers probably did not envision that the dam would even be in operation after 110 years. This act constituted a rare and extreme event (Black Swan) that had devastating impacts. Filling the spillway constituted a geotechnical event or geo-risk that had and is having significant business and financial consequences to all parties involved with this project.

Since these rare, extreme impact, unpredictable events (Black Swans) may occur, the author considers that the only way a firm can protect itself against the financial consequences of these events is by having adequate insurance. Since these events are unpredictable, no amount of training or technical qualifications of the employees can reduce the risk of these events occurring.

In another example, a firm had a construction monitoring assignment but failed to adhere to the agreed upon protocol for reporting its findings. Because of the failure to follow the protocol, the firm was sued for breach of contract by the client and sued by a third party. The insurance company that provided the firm's professional indemnity insurance was the Reliance Insurance Company. The Reliance Insurance rating (Best rating) began to drop in 2000 and in September 2000 the firm cancelled the Reliance policy and obtained insurance with another insurance company. Reliance Insurance Company was ordered into liquidation on October 3, 2001; this was thirteen months after the firm canceled its policy with Reliance. On the above project, Reliance Insurance was notified of a potential claim several months before the policy was cancelled. Because all professional indemnity policies are written on a "claims made" basis, Reliance Insurance was the insurer responsible for this claim. Since the bulk of the legal costs and expenses on the above matter were incurred after Reliance Insurance was forced into liquidation, the firm had to fund all the legal fees, settlement costs, and a trial judgment without having timely reimbursements from its insurance company.

The Reliance Insurance Company was one of the largest property and casualty insurance companies to ever be forced into liquidation in the United States. The rare and extreme impact event in the above case was the combination of the insurance company being forced into liquidation, after the claim was reported, and not being able to pay what it was liable for under the insurance policy. This is another example of a commercial "black swan" in the consulting business.

OTHER BUSINESS RISKS

The business landscape in the consulting fields of geotechnical, mining, and the environmental areas is changing rapidly and these changes present new risks to companies and individual professionals. Some emerging business risks that companies must consider and evaluate are discussed in the following paragraphs.

Personal professional liability -- There are disturbing trends in the interpretation and enforcement of limitation of liability clauses in contracts, particularly on projects where there are only "economic losses." Economic losses are those where there is no personal injury, no third party claims, and the only damages are economic. Many consulting contracts, since the mid-1970s, include a limitation of liability clause. If there are claims that arise out of the contract that are only economic in nature, the aggrieved party's recourse is governed by the contract. In a Florida Supreme Court decision in 1999, Moransis v Heathman [744 So.2d 973 (Fla. 1999)], the court decided that the plaintiff could sue the consulting firm under the contract and sue the individual professionals who worked on that project even though they were employees of the consulting firm that had the contract for the work. The plaintiff was able to sue the professionals in tort for what normally would be a contract dispute.

Subsequently (June 2010), a Florida appellate court found that the limitation of liability clause in a contract between a design firm and its client cannot be applied to limit the liability of an individual professional that is an employee of the firm [Witt v.

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La Gorce Country Club, Inc., 34 Fla.L Weekly D1161a]. Other states have adopted similar interpretations for economic loss matters. This trend creates another expanding business risk for companies and its employees. Most errors and omissions insurance policies obtained by a company cover the negligent acts of the firm and its employees acting on the firm's behalf. Although the employees sued may have insurance coverage under their employer's policy, this trend toward personal liability implies that insurance premiums may increase in the future because of the expanded risk exposure of the insurer.

Professional registration -- As businesses grow, there are opportunities to work for clients in other states or countries; also there may be opportunities to work with professionals in other offices in the same firm on projects. From a business standpoint, professionals and business leaders must ensure that the necessary registration requirements, both individual and corporate, are met before signing a contract or having professionals do design work on projects not in a "home" jurisdiction. For example, if a subject matter expert in a US office, who is registered in his home state, is asked to take the lead role for a design in another country, the registration requirements for that professional must be investigated. If the firm has a local company in the foreign country, can or should the subject matter expert sign a design report or drawings if the design is issued from the local office? Registration requirements, business practices, and contract validity and enforceability may depend on how situations like the above are addressed.

OFAC limitations -- Businesses must also be aware of OFAC limitations on international work. OFAC stands for Office of Foreign Asset Control, a department under the US Department of the Treasury; OFAC enforces economic and trade sanctions against targeted foreign countries. If a project opportunity arises in an OFAC listed country, depending on the sanction, US firms cannot work there and US based insurance companies will exclude coverage for any work done in that country. This can create significant business risks, legal and commercial, if companies elect to undertake assignments in OFAC listed countries.

SUMMARY

A number of different types of business risks have been presented that are typical for firms working in the geotechnical, mining, and geo-environmental areas (geo-risks). Addressing these business geo-risks is quite different than assessing geo-risks on a specific project or for a particular analytical solution. Successful companies must strive to ensure that all components of the geo-risk spectrum, both project risks and business risks, are understood and adequately addressed.

Some of the important issues to consider to help ensure that the broad spectrum of technical and business geo-risks are minimized include:

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- Ensure that an adequate conceptual model is developed, including site characterization, for the specific requirements of the project. Ensure that uncertainty in the model is evaluated if appropriate.
- Ensure that proper deformation and failure mode(s) are identified.
- Ensure that analytical models used have been checked and have gone through a quality assurance process, the model assumptions are understood, and the analyst has experience in doing the analyses.
- Compare model results with more simple predictions to verify the results are reasonable. Make performance estimates before undertaking analytical modeling.
- Ensure that capable and well trained staff are assigned to each task. Ensure that all project personnel know what their scope of work is on each task.
- Audit projects to ensure compliance with company procedures.
- Ensure the technical work is checked and that project technical reviews are done.
- Establish "review boards" for projects as needed. Consider having both internal and external members. The review board members should be involved early in the project. These reviewers should know the scope of work, should approve the work plan elements established by the project team, should review basic data, analytical approach, and analytical results. Review board members should be consulted and have input into the important project decisions.
- On large, long-term projects, periodically review all important assumptions. Ensure the approach being used is reasonable and appropriate. Beware of complacency on the project. Carefully review all monitoring information. Have technical reviews done by professionals not previously involved with the project to get a "fresh" assessment. Carefully assess the technical reviews and evaluate whether changes in the project are warranted.
- Recognize that rare, extreme impact, unpredictable events can and do occur.
- Ensure that the company has an adequate insurance program for the company's needs. Evaluate "self insured retention" limits (deductible amount) and the policy ceiling limits. In considering ceiling limits, recognize that "black swan" events might occur.
- Research the financial health and stability of the firm's insurance company. Balance the insurer's financial health with the quoted premium when selecting an insurance provider.

REFERENCES

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