(01-005) - Designing a way forward from adversarial to collaborative underground engineering: An analysis of Contractual Construction Risk Management

Pérez Reyes, José Anselmo [1]; Jiménez Argüelles, Víctor [2]; Rocha Chiu, Luis Antonio [2]

[1] Universidad Anáhuac, México, [2] Universidad Autónoma Metropolitana (UAM Azcapotzalco)

Underground construction is subject to uncertainties and changes in geological conditions that can cause significant imbalances in public works contracts. This gives rise to various confrontational attitudes among the interested parties, which have a negative impact on the execution time and related costs of the project. In this context, this article discusses, from a conceptual point of view, the relationships that exist between project progress and contractual risk management, as well as the success and mitigation factors as expressed by international experience. In turn, different research proposals are identified that, from a structured approach, analyze the project phases in terms of the contingencies identified in their initiation, development and completion. Based on the management of the illustrated risk categories, the evolution of the construction contract is analyzed from a collaborative and socially committed point of view, with the intention of proposing best practices in this regard.

Keywords: Underground works; public woks contracts; geological uncertainties; stakeholders; contractual risk management

El camino de la confrontación a la colaboración en obras subterráneas: análisis sobre la gestión de riesgos contractuales

La construcción de obras subterráneas está sujeta a incertidumbres y cambios en las condiciones geológicas que pueden provocar desequilibrios importantes en los contratos de obra pública. Lo anterior origina diversas actitudes de confrontación entre las partes interesadas que impactan negativamente en el plazo de ejecución y el costo asociado del proyecto. Al respecto, desde un punto de vista conceptual, el presente artículo discute las conexiones que existen entre el avance del proyecto y el manejo contractual de riesgo, así como los factores de éxito y de mitigación según se expresa a partir de la experiencia internacional. A su vez, se determinarán diferentes propuestas de investigación que, desde un enfoque estructurado, analizan las fases del proyecto en términos de las contingencias identificadas en su inicio, desarrollo y finalización. Finalmente, a partir de la gestión de las categorías de riesgo ilustradas, se analiza la evolución del contrato de construcción desde un punto de vista colaborativo y de compromiso social con la intención de proponer las mejores prácticas al respecto.

Palabras clave: Obras subterráneas; obra pública; incertidumbre geológica; partes interesadas; manejo contractual del riesgo

Correspondencia: Dr. José Anselmo Pérez Reyes, jose.perezre@anahuac.mx

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1. Introduction

The construction contract refers to a written agreement in which the contractor undertakes to perform a work for the owner, in exchange for a price and under certain agreed conditions. In the legal field, it refers to an instrument that establishes the obligations to which the contractor and the owner are subject (Lombardo A. & Reyes J.A., 2016). In this document, a legal agreement is created that establishes the conditions under which the project will be carried out, as well as the scope, delivery terms, payments and, in general, the responsibilities of all parties. Depending on the type of construction, different types of contracts may be chosen, among which the following stand out: the lump sum contract, the unit price contract and the mixed construction contract.

The lump sum contract covers one or more units of work, or the entirety of the works included in the construction project, where the price is established globally on the basis of a closed budget and where this is unchangeable. In such a way that the contractor does not have the right to obtain a higher price if, during the execution of the works, contingencies arise that lead to a higher cost than initially budgeted (Correa Ferrer, P., & García Mekis, B., 2016).

The unit price contract considers a total amount to be paid to the contractor for each unit of design completed and executed according to the project, construction specifications and quality standards. In this type of contract, there is a catalog of items, which is a document that includes the description, unit of measure, quantity, and cost of each unit price, which together make up the total cost of the work. In this type of contract, the work is divided into small fractions and a value is given to each of them (Nazilli, H. B., & Postavaru, N., 2012).

The mixed works contract is a legal instrument that contains services corresponding to contracts of different types. These benefits are combined or coordinated in a single contractual scheme by the action of a mixed cause.

The choice of one or the other legal regime will depend on several factors that will allow a rational and sustainable decision to be made, at least on the following elements: the origin of the resources, the complexity of the executive project, the amount of resources available, whether it is a public or private work, the type of asset to be built, the type of contractor, etc. Generally speaking, the proper planning of the work will lead the parties involved in the construction project to define a tailor-made contract that is balanced in terms of burdens, obligations and rights for the parties involved. The correct formulation of this legal instrument must be such that it has as its main objective the construction of the planned asset.

In the case of underground construction, the main difficulty in achieving overall construction quality lies in the concept of geological uncertainty. Nilsson, B., et al. (2007) define geological uncertainty as incomplete definitions of the conceptual geological framework of a project, where there are temporal and spatial variations that are not fully known by the available data and not fully resolved by a geological model. From a contractual point of view, underground works require the establishment of clauses that allow to face the changes in the geological conditions that may occur during the execution of the works, avoiding conflicts between the parties that affect or stop the development of the works. It is essential to clearly define the responsibilities of the parties and to use all necessary means to reduce geological uncertainties to an acceptable level.

Previous experience and the increasing complexity of underground works have forced experts to design and develop, for the different phases of the project, exploration campaigns appropriate to the importance and complexity of the underground works. From the technical knowledge acquired, specific contracting practices have been defined in order to increase efficiency and ensure the success of the projects. Such is the case of the Emerald Book, a joint work of the International Tunneling Association (ITA) and the International Federation of Consulting Engineers (FIDIC), which developed the first international standard for tunnelling contracts, proposing a balanced distribution of risks between the parties involved in the construction contract (Ertl, H., & Hechenblaickner, K., 2021). The recommendations based on this contractual model comprise international experience and the result of the exchange of knowledge between the various entities involved in the construction of underground infrastructure.

The concept of geological uncertainty implies the need to evaluate possible risk factors, starting from the development of the executive project and extending to the construction phase. Therefore, it is important to recognize the nature and functions of the different actors involved in the construction process, as well as the administrative procedures involved in the programming and awarding of each project. As mentioned at the beginning of this chapter, these actors are the client and the contractor, who, in the case of public works, also include the construction supervisor and the public administration.

Medeiros Schocair, M. (2023) mentions that the overall quality of construction projects requires the identification, minimization, evaluation, and management of the possible risks associated with the project. In the context of underground construction, the Emerald Book suggests that risk management should also extend to the different sections of the tender contract and to insurers. The general classification of risks suggested includes: soil characterization, design, tunneling procedures, geological risks, environment, safety, execution time and cost, durability of works, and collateral damage. In turn, best practices distinguish between long-term and short-term planning, since both cases result in actions and mitigations that must be adapted according to the characteristics, progress, and conditions of the project, and that may contribute to the success or failure of the work.

In the context of underground construction projects, this research work analyzes the possible contractual deviations resulting from the geological uncertainty that characterizes this type of works and examines the relationships that exist between the progress of the project and its potential risks. The research proposal presented here begins in the next chapter with a description of the specific risks identified in the literature for these projects and proposes specific mitigation measures for each case. In the context of public works, it will also be shown that the risk elements associated with the contract can be attributed to political, social and cultural factors. From the above, a series of recommendations will emerge that deal with joint actions that would have a place in an environment that goes beyond the project itself and involves political actors and, in general, the public constituency. On the basis of the foregoing, a conceptual research model will be proposed, according to which the effectiveness of the contracting process, the compliance with the work programs and the construction procedures depend on a cyclic methodology, which documents each phase of the project from the point of view of costs and time, including the impact on others. In turn, it is noted that in order to achieve effective management of the documented risks,

an open register of these risks must be guaranteed to allow effective communication between the parties involved.

2. Contractual risk analysis in underground construction

The proper management of any underground construction project, and even the improvement of existing projects, begins long before excavation. The literature on the subject indicates that the central objective of construction projects is to achieve management that guarantees deadlines and excellence while staying within budget. This is a complex process from initial planning to completion of a project that presents unique challenges involving, among other things, various design interventions, innovative elements, and highly specialized construction techniques (Srivastava, A., et al. 2023).

From a contractual point of view, it is important to note that the main controversies generated in this type of project originate from technically biased management and planning practices (Lombardo A. & Reyes J.A., 2016). However, the competent management of this type of works requires a leadership characterized by confronting them with a holistic approach with an innovative and strategic long-term perspective. In the same context, Hernández R. (2016) indicates that technical experience at the international level is very relevant for this type of projects, but at the contractual level there are many vices that hinder the execution of the works, since the contracts lack a long-term strategic vision and dispute resolution mechanisms that ensure effective communication between the participants of the company.

The construction of underground works presents a series of risks not found in traditional projects. Consequently, their effective management must assume unique elements that evolve according to their complexity. In general, the literature documents essential aspects that must be systematically developed (Zhao, X., 2024). They are highlighted below:

- Define the need for coverage.
- Study the various alternatives.
- Calculate the associated economic costs.
- Identify environmental and social impacts.
- Define the most appropriate alternative.
- Develop a clear and complete contractual framework to address specific challenges.
- Execute and manage contracts from an agile dispute resolution perspective.

Due to its nature, this type of work faces the main element generating technical challenges and contractual disputes during the project: geological uncertainty. This is due to the inadequacy of the geological information collected prior to construction and determined through direct and indirect geological studies in the study area. As a result, this type of project is prone to exceeding the initial budget and the time set for its completion. This is largely due to the fact that the construction procedures may originate from an executive project that failed to mitigate the geological risk as much as possible. It is logical to assume that the greater the investment in the design and foresight phase of the project, the smaller the deviations in the construction program will be.

Therefore, risk management must consider both the most common and the most unusual problems in order to determine the origin of each case and its consequences. Thus, the specific risk analysis for this type of work must analyze all undesirable events, their

probabilities and also their consequences. Documented best practices in this regard (Van Langelaar, A., 2019) allow the classification of specific risks, as shown below in Table 1.

Table 1. Classification of risks in underground construction.

Classification	Risk	Description
Geological Risks	Geological Unpredictability Insufficient geological exploration Inadequate validation and interpretation of the geological model during construction Lack of previous geological information at the site Terrain instability Soil contamination	Related to the inadequacy of the information collected prior to construction and determined through direct and indirect studies throughout the project. Your study must consider the geological, geophysical, geotechnical, geohydrological characterization and the integration of all of them in the profile closest to reality.
Design	Inadequate tunnel support design Inexperience of the designer Inadequate selection of operating ranges, e.g. TBM type TBM Design developed without regulatory framework Lack of local guidelines for the use of underground space. Geotechnical risk Hydraulic risk Structural risk Excavation risk	These are those events or circumstances that may adversely affect the stability, functionality, or safety of the construction project from the time it is designed. These risks are transferred to the construction of the work in the short and long term. They may arise from various factors related to the initial design of the work, the characteristics of the terrain and the geotechnical conditions of the subsoil.
Constructive	Inadequate construction procedures Learning curve Lack of contractor experience Incompatibility of the construction method with the terrain Major mechanical failures Inadequate logistics Geological uncertainty Lack of resources Heterogeneity of the terrain Collateral damage to existing infrastructure Use of inappropriate technologies High demand for skilled labor	These are the risks associated with deviations from the work program and budget. Also related to compliance with project regulations. This type of risk will vary depending on the excavation methodology implemented and the experience gained in the different works.
Contractual	Use of inadequate contracts for the execution of underground works. Lack of specific regulations for the establishment of requirements, specifications and guidelines for underground works. Lack of dispute resolution mechanisms such as Dispute Boards and the Geological Baseline Report (GBR).	These are events or circumstances that may adversely affect the fulfillment of contractual obligations between the parties. These risks can have a significant impact on the cost, schedule and quality of the project and, in some cases, can even lead to litigation or total project failure.
Financial	Suspension of Payments Insurance, licenses, patents Site availability and disposition Construction delay Losses and damages	They refer to those events or circumstances that may adversely affect the profitability or economic viability of the project for the parties involved.

	Strikes and social demonstrations Progress of payments as agreed Financing commitments Bias toward cost evaluation over project safety	
Cultural	Expectations far from reality Poor communication Lack of cooperation Escalation of arbitration when contract disputes arise Confrontational mentality Political factors	Events or circumstances that may negatively affect the development of a project due to cultural differences and procedural biases created by the actions of the parties involved.

Source: Author's

It can be seen that the risks associated with this type of infrastructure can be located throughout the life cycle of the project: planning, design, construction and operation. It should be noted that an additional classification includes risks associated with the type of contract (Loosemore, M., & McCarthy, C. S., 2008). This refers to the choice of contract type, which is related to various factors such as size, complexity of the project, risk appetite of the parties involved, and experience of the contractor. The most relevant risks can be typified according to the type of contract (Nazilli, H. B., & Postavaru, N., 2012).

In the case of unit price contracts, the main risk is related to the uncertainty of the amount of work. That is, the contractor does not know the exact amount of work to be performed until the project is completed. This results mainly in a complex estimation of project costs. However, this type of contracting is suitable for the construction of underground infrastructure, because the more detailed the construction budget is, the smaller the deviations in the construction. It should be noted that geological uncertainty plays an important role in the quantification of works, so it is desirable to reduce this uncertainty in the executive project stage.

Under a lump sum contract, the contractor assumes the risk of quantifying his own work, since he cannot change the estimated quantities once the project is awarded. This type of contract offers the client the certainty of a known final amount, which facilitates the financial planning of the project. Therefore, the main reasons that may cause a deviation in this type of contract are related to errors in the cost estimate and some unforeseen events such as an increase in the price of materials and delays for reasons beyond the control of the parties involved. Therefore, this type of contract can be a good option for projects where the scope of work is well defined or for the preparation of executive projects. Due to its nature, this type of contract is not suitable for the construction of underground infrastructure.

During the contracting process, there are external factors that have a strong influence on the evolution of construction contracts. Usually, underground works are government projects (Hernández R., 2016) and this means that they are susceptible to risk elements coming from the interested parties. In particular, the administrative laws of some countries are extremely restrictive and this results in a natural tendency on the part of the contracting entities to develop projects through very restrictive regulatory schemes that are not suitable for highly complex works, as is the case of underground infrastructure.

Regulatory problems are not the only exogenous factors that can be identified (Zhao, X., 2024). There is also a political factor that has a significant impact, since these are usually

public works that depend on the allocation of resources and the definition of priorities. Therefore, a stable and efficient political environment is necessary for the efficient development of this type of infrastructure.

It is possible to understand that effective decision making in underground works depends not only on a technical profile that conceives the solution of problems based on scientific principles and practical considerations, but must also be complemented by a training that adopts dialogue and contractual knowledge as crucial elements for the correct development of the construction.

3. Development of a conceptual model for contractual risk management in underground construction

From the previous chapter, it is clear that effective contract management for underground construction is critical to the success of these projects. This is mainly due to the unique challenges of geological uncertainty, safety risks and technical complexity (Choi, H.-H., et al., 2004). Therefore, this chapter proposes a collaborative conceptual model that gathers the best documented practices in this area and seeks to guide the parties involved in the planning, execution and control of these projects, with the intention of minimizing the risks and maximizing the chances of success. This will be developed below based on the description of 5 research proposals.

The correct planning and selection of the contract is considered a crucial step in establishing a clear and detailed scope of the project, and this should include the technical specifications and quality requirements specific to underground infrastructure (Sarah H. Wilson, 2019). It is important to note that the relationship between the client and the contractor is complex, especially due to the mediation of stakeholders.

In the case of public works projects, the contractor is complemented by the management of supervision, media, audit and specialized advice, which entails a high level of control that forces the involvement of the contractor in processes exogenous to the construction contract. This can lead to disputes and claims that increase the risks inherent in the project. According to Lombardo A. & Reyes J.A. (2016), factors exogenous to the construction of public works can include elements such as expectations that are far from reality, ambiguous contract terms, poor communication between the parties, lack of cooperation, escalation of mediations, and a mindset that is biased towards confrontation between the parties. From the above, the following research proposal stands out:

Rp_1. Effective contract management for underground construction depends on a proper design and contract selection process that includes a clear definition of the scope of work, selection of the most appropriate contract, and establishment of a realistic budget, which can only be achieved if a thorough geological investigation is performed in the execution project.

Project planning, design, subsequent procurement and construction are typically treated as separate entities under the responsibility of different entities, resulting in significant risk due to the lack of integration between stakeholders (Anspach, J., 2018-a). This can lead to very costly problems in terms of time, quality, price and safety of the work. For these reasons, proper risk management is crucial and should be conceived as a continuous adaptive process that is subject to the naturally changing conditions of the underground construction

site. Effective risk management enables stakeholders to make informed decisions to reduce the likelihood of adverse events and thereby minimize the impact on the project. Based on the above, the following research proposal is suggested.:

Rp_2. The risk management model for underground construction should include the specific identification and comprehensive assessment of risks, as well as the development of mitigation strategies that include continuous monitoring and control of identified hazards.

Effective communication between stakeholders in underground construction projects is crucial for their success (Hernández R., 2016). If it is achieved, it can improve the safety of the work, its efficiency, quality, customer satisfaction and achieve an adequate management of project risks. It should be noted that the inherent complexity of this type of work requires the generation of a leadership that has a precise knowledge of all the variables of the work, which will result in a safer work environment that adds value and minimizes risk. For these reasons, the following research proposal emerges.

Rp_3. Proper communication and collaboration between stakeholders in underground construction projects will be effective as long as effective communication channels are established with a collaborative and problem-solving approach.

Any underground work, considered as a project with unrepeatable characteristics, must consider a strategic plan robust enough to determine the key performance indicators that evaluate the effectiveness of the actions implemented in the event of any contingency. This can be achieved through the use of quantitative metrics (Key Performance Indicators, KPI's) that allow improving the performance of the work based on sound decision making (PR Newswire., 2024, March 14). Given the nature of these projects, the characteristics of their KPI's must be relevant, specific, measurable, achievable and temporary indicators. Based on the above, the following is proposed:

Rp_4. An effective performance management and quality control system for underground infrastructure construction is characterized by the establishment of clear and measurable performance indicators tailored to the unique realities of the construction site.

Underground work projects are complex and involve a high degree of risk, which increases the likelihood of disputes between the parties involved. Hernández R., (2016) shows that the clear knowledge of the technical problems that arise in the work is not enough to resolve the disputes that arise between the parties involved. It is necessary to generate sufficient contractual spaces and mechanisms to resolve them. These should focus on negotiation and mediation, so that disputes arising during project execution can be resolved amicably and efficiently. Best practices suggest the establishment of a so-called Dispute Board (DB), which refers to the accompaniment of 3 experts, usually engineers and specialized lawyers, who have sufficient experience in underground construction projects.

The DB must be familiar with the contract and the project as a whole and be attentive to its execution. When called upon to make a recommendation in the context of a dispute, it must act as an independent and neutral entity that privileges the execution and continuity of the project (Kamprath, M. T., 2014). Therefore, DBs are an effective tool for resolving disputes in these types of projects quickly, efficiently, and cost-effectively. Their use can help prevent

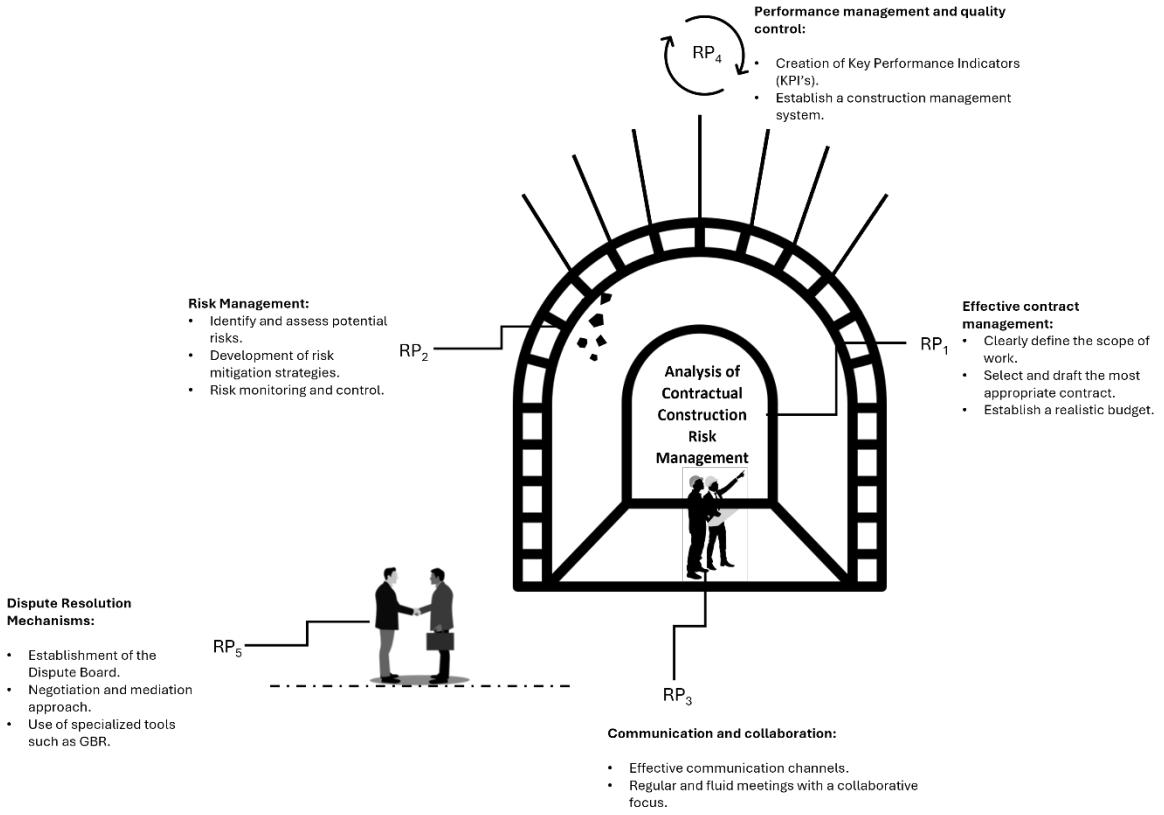
costly and protracted litigation, preserve business relationships between parties, and reduce costs associated with dispute resolution.

An essential dispute resolution tool is a document called the Geotechnical Baseline Report (GBR), whose purpose is to incorporate into the contract the geological, geotechnical, and structural analyses that provide the basis for identifying potential risks associated with the construction phase of a project. This section of the contract contains the pre-construction technical information and establishes a study aimed at optimizing the design of the structures and the excavation process. From this, it lays the foundation for the geotechnical and financial risk distribution of the work (Anspach, J., 2018-b). From the above, the following research proposal is formed.:

Rp_5. The resolution of disputes and controversies in underground infrastructure projects is optimized by including dispute resolution mechanisms in the contract, such as Dispute Boards (DBs), which focus on negotiation and mediation between the parties.

With the intention of linking the aspects described in each of the research proposals and that they help to understand how, as a whole, they contribute to an effective contractual management of underground projects, Figure 1 shows the relationship between the variables described and how they could maximize the probabilities of success for this type of projects.

Figure 1. Conceptual model of contractual risk management.



Source: Author's

The above model assumes a permanent management process adapted to the construction of underground works, which, as has been recognized, involve a complexity inherent to the risks already described in Chapter 1. Thus, the proposed conceptual model considers the specific characteristics of this type of projects and proposes a concise methodological framework for the identification, assessment, mitigation and monitoring of the risks described.

It is worth noting that the model shows that in order to achieve continued success throughout the life of the project, it is important to define clear commitments among stakeholders. This includes assigning a person responsible for risk management, defining the roles and responsibilities of each stakeholder, and establishing communication and coordination mechanisms between the different project entities.

4. General Discussion

Underground infrastructure projects are complex and have a high degree of uncertainty, which generates various problems that often lead to an economic dilemma that must be resolved through a legal mechanism. Considering that most of them are promoted and built by the government (public works), political and financial distortions must be assumed,

resulting in works that are burdensome and of long duration. Therefore, this type of project requires a significant and long-term investment, which, once carried out, is not fungible and becomes critical due to the time factor, to which is added the variability generated by geological uncertainty.

This can give rise to controversies, the resolution of which requires the drawing up of sophisticated contracts that speed up the solution of technical problems but also considers the economic and regulatory regulation of public works. It is important to note that, at the same time, it is necessary to combine the interests of all interested parties, who may or may not have the same sensitivity and proximity to the work in question. In this respect, the establishment of dispute boards is very useful.

However, experience has shown that no matter how detailed underground infrastructure contracts are, unforeseen problems often arise (Coffee, J.D., 1988). Economists call this the theory of incomplete contracts (Pacala, A., 2012). Thus, drafting a detailed contract is never enough to mitigate the problems that arise from naturally changing geology.

The classification of risks described above makes it possible to assume that many of them must be assumed as shared risks. This means that the parties involved in the construction contract share the risks as well as the benefits of the project. Therefore, it is desirable that the joint action of the stakeholders is aimed at reducing the cost of construction by finding a more equitable way of risk sharing.

It is important to note that underground works require specialized resources for their construction (Reilly J. J., 2000). This means that potential contractors must have proven technical and financial capabilities that will result in safe construction without significant delays. Therefore, the procedure for awarding a contract must consider reasonable grounds and fair procedures. This means that the contract should be awarded to companies that demonstrate the capabilities described, and never to the lowest bidder. Awarding such a contract on the basis of apparent savings would lead to costly disputes that would be detrimental to the interests of all parties.

Each project must include a sufficiently robust strategic plan in terms of risk identification and mitigation processes. However, the effectiveness of such plans may also depend on a number of specific social and political constraints that affect the circumstances of the project's development. For example, the decision to implement one type of technology or another depends to a large extent on economic decisions and the budget allocated to public works. This is to the detriment of performance, which in any case is the responsibility of the contractor.

Geological uncertainty is a latent risk in the construction of this type of project. It leads to a constant adjustment of the contract prices, so it is convenient that the contract includes some clauses that include mitigation measures for changes in geological conditions. This allows contractors to avoid including large contingency amounts in the tender bids, as this would allow them to properly analyze the available information and make a bid where the cost of the project is not affected by assumptions during excavation.

It should be noted that the actual geological conditions of the project can only be determined during the excavation process, therefore the geological unpredictability is the responsibility of the contractor. In case of encountering conditions different from those estimated, the

Contractor shall inform the Principal in a timely manner in order to agree and conclude whether there are indeed differences and, if so, to reconcile and establish the basis for appropriate compensation. In this context, the use of the Gotechnical Baseline Report is essential.

5. Conclusions

Based on the documented international experience in the construction of underground infrastructure, this article has shown the factors that influence the identification of risks associated with construction. Therefore, solutions have been addressed that have benefited the effective management of works and the mitigation of identified risks. It was pointed out that the continuous technological development, the implementation of new strategies and methodologies have improved the safety and efficiency of works.

In turn, the conceptual model developed here showed that the mitigation of contractual risks does not depend solely on the modification of laws or the generation of sophisticated contractual clauses. It also requires a reformulation of the entire system surrounding the contract.

One aspect to emphasize is the importance of teamwork and the creation of leadership with a holistic approach. If this is achieved, it is possible that the planning, design, procurement, and construction phases will result in a collaborative effort that proposes common solutions that minimize the controversies inherent in this type of project. Therefore, the value proposition that results from the unique offer that the contractor provides to its client must consider the establishment of various communication channels between the interested parties and be directed to the benefit of the project, considering it as the most relevant entity.

Due to the conceptual scope of this research, it is suggested that empirical studies be developed to support the research proposals described and to verify the effectiveness of the forms of collaboration identified among the stakeholders.

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