Development of a Risk Management Framework for Tunnel Construction in India

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Abstract—The growth of Tunnel Construction industry made significant improvement over the past few decades. This is fundamentally due to the increasing investments in road, rail and hydropower sectors. However, the tunnel construction industry in our country faces many challenges. This many a times lead to the incompletion of these projects, and ultimately its cost overrun and time overrun. A successful tunnel project is possible only if the risks associated with the project are identified, evaluated and managed. The main objective of this paper includes risk assessment and management of tunneling projects in developing countries like India. The procedure followed in this paper involves risks identification through literature surveys and interviews with experts, preparation of risk questionnaire to determine probability and severity of risk involved in various phases of the project, analysing the risks and suggesting risk mitigation measures for the major risks involved in the project. Case studies are also carried out to give a better insight in to the study.

Keywords—Risk Analysis, IMP.I(Importance Index Technique), Risk Matrix, Risk Register, Tunneling Projects

I. INTRODUCTION

Tunnelling as a unique branch of civil engineering is described by high dangers during project execution. Tunnelling and underground construction works impose hazards on all parties involved not only on those directly engaged with the task. Especially in residential areas the effect has been drastic on the local residents as well as on the surrounding buildings.

The inherent risks include ground and groundwater conditions, cost overrun delays, large scale accidents also there is a risk that problems which the tunnel project cause to the public might result in public protest which may affect the project. These risks are generally solved through appropriate risk assessment and risk mitigation methods. However, the lack of appropriate methods of risk management in our country has led to the cost overrun and time over run of many of the tunnelling projects. The application of risk assessment and management in the tunnel construction industry is the need of this time due to the ever increasing complexity of the tunnelling projects and due to the ever increasing pressure for cost reduction and construction duration reduction.

II. OBJECTIVES

The main objectives of this paper are:

- To identify the major internal and external risks that affect the growth of the tunnel construction industry.
- The evaluation of risks so as to prioritize them for effective risk management.
- Development of a risk management model which uses appropriate techniques to reduce risks in tunnelling.

III. LITERATURE SURVEY

- Rakhi Arora et al. (2016), identified various technical risks encountered with at the time of excavation. The instability of the ground is one of the main dangers that must be catered to do. It arises due to adverse orientation of the joint and fracture plane and due to the presence of cohesive sands. A case study was also conducted at Azadpur where during excavation bed rock was discovered instead of continuous soil strata.
- Cagatay, (2015) in his paper has proposed what the hazards that would be encountered during tunnel construction by Tunnel Boring Method (TBM) are. A Hazard Analysis is conducted to sort out and categorise risks with high scores. The results showed that hazards with high scores were basically of these four categories which include excavation, support induced accidents geological conditions axillary works and project contract.
- Vishal Kumar Gupta et al. (2017) mentioned in their study that the risk management techniques of Indian Construction companies have large setbacks for the process, since it was evident from the time and cost overrun numbers. They highlighted the risk factors involved in typical tunnelling which include the construction risk, management risks, political, social economic risks and force majeure. Risk quantification methodologies such as Monte Carlo Simulation (MCS) and Judgemental Risk Analysis (JRA) process were proposed. A case study was conducted to apply the proposed risk quantification methodology to help organisations.
- Surabhi Mishra et.al. (2016) in their study suggested various critical risk factors involved in construction projects. Basically, risks were classified as engineering and non-engineering risks. The former is predictable while the latter is unpredictable. Hence those risks that are predictable should be forecasted in the initial phases of the project. The unpredictable risks should also be taken into account so to avoid substantial negative effects on the cost, time and quality of the project. It was concluded in this study that identifying risks earlier during the initial phases of construction will lead to accurate findings about cost and time overrun
- Soren Degn Eskesen et al. (2004) put forward guidelines for risk management in tunneling. This topic elaborates on how modern-day industries practise risk assessment. It describes the stages of risk assessment throughout the project cycle right from the conceptual
stage including the early design phase, Tendering and Contract negotiation phase and the execution phase. It also contains some general components of risk management and a brief introduction to the typical risk management tools.

IV. RISK MANAGEMENT FRAMEWORK

Risk Management is a systematized method of identification, analasation and response to project risk. In other words, it is a maximization of the probability and outcomes of positive events and minimisation of the probability and outcomes of negative events on the project objectives. Refer to Fig. 1 for the flow chart of a risk management framework.

V. RISK IDENTIFICATION

Risk identification is the process of identifying the risks that affect the project objectives. It is an iterative process in which the first step is done by the risk management team, the second iterative process is done by the primary stakeholders and the final iterative process is done by persons who are not in the project. In this paper risks affecting the tunneling projects were identified through literature surveys, case studies and by conducting interviews with experts in the field of construction. The risks identified are shown in the Table 1.

VI. RISK ANALYSIS

It is the process in which risks are prioritized based on their effect on project objectives. The inputs in the process would include the identified risks and assumptions. After using the appropriate tools, the output is obtained i.e. a risk ranking for the project. The technique used for risk analysis in this paper is Importance Index (IMP.I) Technique.

A. Questionnaire Survey

Basically, experts are selected from the group of people who have experience of being consultants in the construction field. A questionnaire was prepared based on the identified variables from various literature surveys and exert judgements. It was made in three sections.

Table I. RISK BREAKDOWN STRUCTURE

| EXTERNAL RISKS                          | INTERNAL RISKS                          |
|----------------------------------------|----------------------------------------|
| Change in government policies which adversely affects the project | Design faults |
| Strikes and labour disputes            | Cave in collapse                        |
| Inflation/price escalation             | Tunnel flooding                         |

Table II. LIKERT SCALE FOR PROBABILITY OF OCCURRENCE

| Rare  | Unlikely | Possible | Likely | Most likely |
|-------|----------|----------|--------|-------------|
| 1     | 2        | 3        | 4      | 5           |

Section 1 covers the personal details. It includes the personal information like Name of the respondent, type of the organization he/she belongs to, type of work his/her organization does, His/her position in the organization and their construction experience.

Section 2 covers the external risks attained from the reports. Responses on external risks regarding its frequency and severity were collected on Likert scale of 1 to 5.

Section 3 covers the internal risks attained from the reports. Responses on internal risks regarding its frequency and severity were collected on Likert scale of 1 to 5.

Basically, a five point Likert scale is used for the analysis of risks in this project as shown in Table II and Table III. The definition for different ratings given for the likelihood of risk is given in Table IV (Pumann et al., 2008). The definition for different ratings given for the impact of risk on cost and time of project is given in Table V and Table VI as referred from the Project Management Book of Knowledge (PMBOK). The experts were asked to rate the risks on a scale of one to five. The frequency of occurrence and the impact on both cost and time were analysed.
Respondents include experts in the field of construction which includes site engineers and construction managers. The range of experience in the field varied from 2 to 20 yrs. Respondents were targeted through random sampling. Questionnaires were sent by mail or given personally. Since the experts of greater years of experience have better knowledge, their responses are being given greater weightage as shown in Table VII below.

### Table VII. Weightage Given to the Response Collected

| Sl. No | No of years of experience in the construction field | Weightage | No of responses |
|--------|--------------------------------------------------|-----------|----------------|
| 1      | 0-10                                             |           | 17             |
| 2      | >10                                              | 2         | 28             |

**B. Importance Index (IMP.I) Technique**

In this technique the calculations are done by measuring the severity index and frequency index as below. (Mamata Rajgor, 2016)

Frequency Index: A formula used to rank risk based on the frequency of occurrence as identified by the participants.

\[
\text{Frequency Index (F.I) } (\%) = \frac{\sum n(N)}{100/5}
\]

Where a is the constant expressing weightage given to each response (ranging from 1 for insignificant to 5 for extreme) n is the frequency of response and N is the total number of responses.

Severity Index: A formula used to rank risk based on the severity of occurrence as identified by the participants.

\[
\text{Severity Index (F.I) } (\%) = \frac{\sum b(N)}{100/5}
\]

Where b is the constant expressing weightage given to each response (ranging from 1 for insignificant to 5 for extreme) n is the frequency of response and N is the total number of responses.

### Table III. Likert Scale for Severity of Risks

| Insignificant | Minor | Moderate | Major | Extreme |
|---------------|-------|----------|-------|---------|
| 1             | 2     | 3        | 4     | 5       |

### Table IV. Definition of Various Frequency Rating of Risks (Pumann et al, 2008)

| A       | B       | C       | D       |
|---------|---------|---------|---------|
| Rare    | Occurs once in a duration greater than 5 years |
| Unlikely| Occurs once in 5 years                          |
| Possible| Occurs once a year                              |
| Likely  | Occurs once in a month                          |
| Most Likely | Occurs frequently in a week                  |

### Table V. Definition for Impact of Risk on Project Cost (PMBOK)

| Insignificant | Insignificant cost increase |
|---------------|----------------------------|
| Minor         | <5% cost increase          |
| Moderate      | 5 to 10% cost increase     |
| Major         | 10 to 20% cost increase    |
| Extreme       | >20% cost increase         |

### Table VI. Impact of Risk on Project Schedule (PMBOK)

| Insignificant | Insignificant schedule slippage |
|---------------|---------------------------------|
| Minor         | Schedule slippage < 5%          |
| Moderate      | Schedule slippage 5 to 10%      |
| Major         | Schedule slippage 10 to 20%     |
| Extreme       | Schedule slippage greater than 20% |

### A. Total of 100 questionnaires were sent and feedback from 71 experts was received. Out of the 71 responses 45 were complete and 26 were incomplete yielding a completion rate of 63%. It is satisfactory for the purpose of this research. In addition to these surveys, face to face interviews were also conducted with consultants and designers.

### C. Risk Matrix

A risk matrix is also known as the severity matrix and it helps to improve the visibility of risks. A risk matrix is an important tool that has to be implemented in every project that are critical to the exposure of risks. A risk matrix consists of a series of squares and each risk is assigned a square based on its corresponding frequency and severity. Fig. 2 is an example of a typical risk matrix.

### Table VIII. Ranking Based on Severity of Cost

| RISK ID | RISK FACTORS | FREQUENCY INDEX | SEVERITY INDEX | IMPACT INDEX | RANKING |
|---------|--------------|-----------------|----------------|--------------|---------|
| R1      | Change in government policies which adversely affects the project | 0.66 | 0.69 | 0.45 | 6 |
| R2      | Strikes and labour disputes | 0.73 | 0.63 | 0.46 | 5 |
| R3      | Inflation/pric e escalation | 0.77 | 0.71 | 0.55 | 2 |
| R4      | Land disputes | 0.71 | 0.66 | 0.47 | 3 |
| R5      | Site condition causing problems- Loose soil, hard soil etc | 0.76 | 0.75 | 0.57 | 1 |
| R6      | Site condition causing problems- High water table | 0.69 | 0.65 | 0.45 | 7 |
| R7      | Landslides getting working buried, Earthquakes, Storms, Floods | 0.65 | 0.68 | 0.44 | 9 |
| R8      | Design faults (design by) | 0.62 | 0.70 | 0.43 | 11 |
By referring to the risk matrix in Fig.2 we can categorize the risks on both cost and time as in Fig. 3 and Fig. 4.
Extreme risks are those that have the highest impact indices. The extreme risks as observed from the risk matrix are graphed in figures Fig.5 and Fig.6 as below:

By comparing both the tables above we find that, the critical risks that cause serious impact on cost and time are similar. Though there are various factors that affect the smooth progress of tunnelling, the most critical that are common in most projects and result in the cost and time overrun include: Change in government policies, strikes and labour disputes, inflation, site problems force majeure, design faults, cave in collapse lack of cash flow. delay in approvals and delay in mobilization of resources. Moreover almost all the risks identified through the survey come either in the high or extreme risk category. Hence proper response strategy and proper preparedness is required to manage all the risks identified. It is clear from the above study that the critical risks are those that are mostly from the external sources. Though the external risks are caused due to reasons not linked with the project and it is beyond the control of the project manager, safety measures can be implemented that helps in reducing its impact on the project objectives. The strategy to manage these high and extreme risks should be carefully selected since the success of the project depends on the capacity to face risks.

VIII . CASE STUDIES

Since this project is concerned with the risk management in our country, a better understanding can be possible only through going through various tunneling projects that had been undertaken here. Some of the various tunneling projects that faced challenges are included in this case study and they include BMRCL tunnel Phase I, Atal Tunnel and Kuthiran Tunnel.

From Table XI it is clear that the risks faced during the execution of these projects are same as the extreme risks that was obtained in our risk analysis earlier. Since these risks were not identified in the earlier stages of the project, they caused adverse impacts on the project objectives such as time cost and quality. Hence proper risk identification and response techniques are required for the successful completion of the tunnel construction projects.
| Risk ID | Risk Description | Ranking based on cost | Ranking based on Time | Risk Owner | Response Strategy | Details |
|---------|------------------|-----------------------|-----------------------|------------|-------------------|---------|
| R5      | Site condition causing problems- Loose soil, hard soil etc | 1 | 1 | Owner | Mitigate | • Confirmatory geological investigation done in detail with appropriate focus on the GBR and GDR reports. |
| R3      | Inflation /price escalation | 2 | 4 | Contractor | Transfer | • Escalation Clause | • Price contingency in the bid |
| R4      | Land disputes | 3 | 3 | Owner | Avoid | • Careful site selection backed by investigation of history. | • Addressing all environmental issues before the bid process, including impact assessment. |
| R9      | Cave in collapse | 4 | 10 | Contractor | Avoid | • Provide adequate shoring to prevent collapse of soil, this should be regularly checked. | • Community consultations to ensure least resistance from local population. |
| R2      | Strikes and labour disputes | 5 | 2 | Owner | Mitigate | • Use risk monitoring tools to track labour issues | • Bridge the gap between the labour and the management |
| R1      | Change in government policies which adversely affects the project | 6 | 7 | Owner | Accept | • Develop plans for emergency situations like wars | • Political risks can be insured against through international agencies and government bodies |
| R6      | Site condition causing problems- High water table | 7 | 9 | Owner | Mitigate | • Confirmatory geological investigation done in detail. | • Dewatering by well point technique done to prevent accumulation |
| R14     | Change orders/ Deviation proposals | 8 | 12 | Owner - Contractor | Avoid | • Establish a quality control process | • Increase coordination between the owner and contractor |
| R7      | Landslides getting working buried, Earthquakes, Storms, Floods | 9 | 13 | Owner | Transfer | • Insure all force majeure risks. | • Obtain Governments guarantees to adjust tariff or extend concession period. |
| R25     | Delay in approvals | 10 | 5 | Owner/Contractor | Avoid | • Flexibility should be maintained in the timeline. | • Identify and document the source of delay and find solution |
| R8      | Design faults (design by the contractor) | 11 | 11 | Architect | Mitigate | • Performance Guarantee | • Preparation Bond |
| R15     | Lack of cash flow | 12 | 6 | Contractor | Mitigate | • Create a cash flow projection for the project so to monitor well | • Hire experienced surveyors and designers for design |
TABLE XI. CRITICAL RISK FACTORS OF VARIOUS TUNNEL PROJECTS

| SI No | Critical Risk Factors                                                                 | BMRCIL Phase 1 Tunnel Construction 2017 | Atul Tunnel (2014) | Kuthiran Twin Tunnel |
|-------|----------------------------------------------------------------------------------------|----------------------------------------|--------------------|---------------------|
| 1     | Site condition causing problems- Loose soil, hard soil etc                            | ✓                                      | ✓                  | ✓                  |
| 2     | Inflation /price escalation                                                           | ✓                                      | ✓                  |                     |
| 3     | Land disputes                                                                         | ✓                                      |                     | ✓                  |
| 4     | Cave in collapse                                                                      | ✓                                      |                     |                     |
| 5     | Strikes and labour disputes                                                           | ✓                                      | ✓                  |                     |
| 6     | Change in government policies which adversely affects the project                     | ✓                                      |                     |                     |
| 7     | Site condition causing problems-High water table                                      | ✓                                      |                     |                     |
| 8     | Change orders/ Deviation proposals                                                     | ✓                                      |                     |                     |
| 9     | Landslides getting working buried, Earthquakes, Storms, Floods                       | ✓                                      |                     |                     |
| 10    | Delay in approvals                                                                    | ✓                                      | ✓                  |                     |
| 11    | Design faults (design by the contractor)                                              | ✓                                      |                     |                     |
| 12    | Delay of mobilization of resources                                                     | ✓                                      | ✓                  | ✓                  |
| 13    | Lack of cash flow                                                                     | ✓                                      |                     |                     |

IX. RISK RESPONSE MONITORING AND CONTROL

Risk Monitoring is a process that ensures that the identified risks are taken into consideration for their proper disposal. In other words, it’s a process of developing alternatives to increase the opportunities and to reduce the threats to the project objectives. After completing the process of identifying, analysing and prioritising the risks a risk response can be developed to avoid the risks. The basic process involves to identify assign risk owners to take responsibility for the risks identified. It basically addresses risks based on their ranking or priority (PMBOK). A risk response plan is created as in Table X

Risk monitoring and control is the last step in the risk management process. It takes place throughout the life cycle of the project. As the project proceeds through various stages new risks come into being. Proper risk monitoring is required for identifying risks from time to time. This also helps in anticipating risks well in advance. Proper communication with all stakeholders is required for the periodical assessment of risks. The risk owners should keep the project manager informed from time to time about the effectiveness of the plan.

X. CONCLUSIONS AND RECOMMENDATIONS

Since risks from external sources are the most critical ones and due to the fact that they are beyond the control of the project, appropriate risk transfer strategies have to be given more importance. Risk management plan should be started off early in the project conception stage and its activities should be carried out throughout the course of the project. Moreover, secondary and residual risks should be identified from time to time and they should be updated in the risk register. Another important principle that should be kept in mind during risk management is that the cost of mitigating or avoiding the risk should not be greater than the cost of the risk itself.

Some recommendations for future research include qualitative analysis of the risk identified and verifying the validity of the model. In this study only a qualitative analysis was done, so it can be used as an aid for a quantitative analysis of risks in tunneling. Due various constraints the validity of the proposed model was not checked. A proposal can be put forward for verifying the validity of the model. This concept is generic and hence we can extend this concept to fields other than tunnelling such as hydropower, bridges, nuclear and power plants.

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