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Hazard Identification, Risk Assessment and Control (HIRAC) in Elevated Metro Construction Project

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Abstract - *To organize the transportation system in major cities of India and to reduce the traffic from road the Government of India and the state governments are emphasizing more on the public transportation mode through metro. With the increase in demand and deadlines to meet, the construction of metro projects is exposed to many hazardous activities. Since the construction of metro projects are always located in the center of congested cities alongside the active roads, they possess very high potential of any mishap or accident with the neighboring buildings and underground covered-up pipelines. The research aims to determine the hazards during the construction phase of metro using Hazard Identification and Risk Assessment with Controls (HIRAC) approach. The objective of using this approach is to achieve a safer and healthier working environment during the construction stage of metro. The expected outcome of using this approach is the identification of underlying task specific hazards and formulation of their respective control measures to mitigate or minimize the risk they possess.*

***Key Words*: Hazard Identification, Risk Assessment, Metro Construction, Work zone safety, AHP, HIRAC**

1.INTRODUCTION

1.1 Transport network in India

India is only second to China in terms of population in the world and more than one-third of India's population in residing in urban areas making it heavily dense. The transportation system of India is one of the largest in the world that covers land mass of 3.3 million square km with a population of over one billion. In the past decade, the metropolitan cities in India have started adopting bus rapid transit system (BRTS) and rapid transit (MRT) metro system to make the public transportation non-disruptive and more efficient.

1.2 Mass Rapid Transit System (MRTS)

The unprecedented proportion of urban population growth and unplanned exponential growth of vehicles on the road with insignificant increase in road space resulted in Billions of important man-hours being lost with people stuck in dense traffic.

Mass Rapid Transit System provides a new approach with high-capacity public transport. The mass transit systems in urban group can be generally categorized into the following five classes:

•Bus-ways and Bus Rapid Transit System (BRTS):

Bus-ways are fixed bus lanes alongside the main traffic lane with a separated passageway for movement of buses only. BRTS is an improved type of a bus-way which includes attribute such as amenities for pedestrians and Non-Motorised Vehicles.

•Light Rail Transit (LRT):

LRT is in general rail centered mass transit system which is by and large separated from the main roadway.

•Tramways:

Tramways are rail based system that are not separated and frequently move in along with mixed traffic surroundings.

•Metro Rail:

Metro rail is an entirely separated rail based mass transit system, which may be at grade, underground or elevated. Owing to its corporeal isolation and system machinery, metro rail has extraordinary capacity of 40,000 to 80,000 commuters per hour per direction.

Xing et al., (2019) presented a domain ontology "SRI-Onto" to formalize and standardize the safety risk identification and safety risk knowledge in metro construction. The five step ontology development methodology organizes the knowledge of safety risk into seven classes namely "project, construction activity, risk factor, risk, risk grade, risk consequence and preventive measures". Protégé platform is used to edit the classes and to define the relations through coding. The evaluation of "STI-Onto" on the basis of criteria showed that the domain ontology adopted is correct and concise in filling the knowledge gap. Also it proved out to be immensely helpful in facilitating knowledge sharing and semantic inter-operability among different computer applications. The author concluded with the statement that by using the aforementioned approach, reduction in metro construction risks can be achieved thereby enhancing the construction safety level.

Wang & Chen, (2017) presented a systemic decision-support approach that aids in performing safety risk analysis by the combination of fuzzy comprehensive evaluation method (FCEM) and Bayesian network (BN) to thoroughly evaluate and mitigate the innate risks associated with metro construction. The outcome of the research touched three critical aspects which are risk probability, risk loss and risk controllability. In the adopted methodology, probability of risk was computed using bayesian network with the help of directed graph whereas risk loss and risk controllability were evaluated in terms of fuzzy numbers using FCEM. The applicability and feasibility of the proposed approach was verified by applying it to the construction of the Dalian Metro in China. The outcome of the approach is later compared with the actual construction scenario which proved its effectiveness in approximating the risk level of a metro construction project.

Izumi et al., (2014) implemented the onsite visualization (OSV) monitoring approach using laser pointer and light-emitting inclination sensor (LEIS) to screen the safety conditions during construction of Okhla cantilever bridge in Delhi metro project. The most important tool used by the authors for monitoring, sensing and capturing the unique behaviour of the long span bridge under construction is light-emitting sensor that can provide on spot visual output of measurement in unprecedented manner.

Sarkar & Singh, (2020) developed an integrated approach that uses the Fuzzy Failure Mode and Effect Analysis (FFMEA) and Fuzzy Expected Value Method (FEVM) to determine the risk severities of the risks accompanying the construction of elevated corridor of metro rail project in Ahmedabad, India. Initially the author had conducted site and data survey to determine the underlying risk in different stages and activities during the construction of elevated metro project with the help and guidance of experts and pre-planned questionnaires. In the second stage of research, the authors analysed the identified risk for their likelihood, severity and detectability in order to compute the risk priority number. In the third stage of research, the authors ranked the risk on the basis of risk priority score. It was brought into light through the results that land acquisition, feasibility, tendering, segment erection, segment casting, obligatory span, construction planning, launching girder, road widening, piles and piers activities were highly risky for which appropriate risk mitigation measures were proposed by the authors.

Zhou et al., (2013) proposed a 4 dimensional visualization approach for management of safety and assessment of risk in underground construction of metro project. Information from the grassroot level has been analysed by the authors to articulate a 4 dimensional (4D) model of the construction site. The approach uses a rule-based tool that analyzes the information and spontaneously detects potentially hazardous activities and situations and offers instructions for correction. Also, continuous comparison is carried out between the developed model and actual site monitored data. The results obtained proved that the approach used can be used for virtual analysis and prediction by the designers and site managers. The real-time visualization of site reveals the underlying risk before and during construction process that includes continuous evolving level of safety risks. It also helps in the identification of improper construction procedures through simulation helping the site managers to take prompt actions.

1.3 Details of Sites Surveyed

To identify the hazards and to assess their corresponding risk, frequent site safety survey was carried out for a period of 7 days. The objective of conducting the site surveys were to note down the details of unsafe acts carried out by the workers/ operators/drivers and unsafe working conditions that may lead to an unwanted fatal accident. The project mainly covers eight major construction sites where metro station has to be built. The safety survey is proposed to be carried out throughout the length of project wherever construction work is going on.

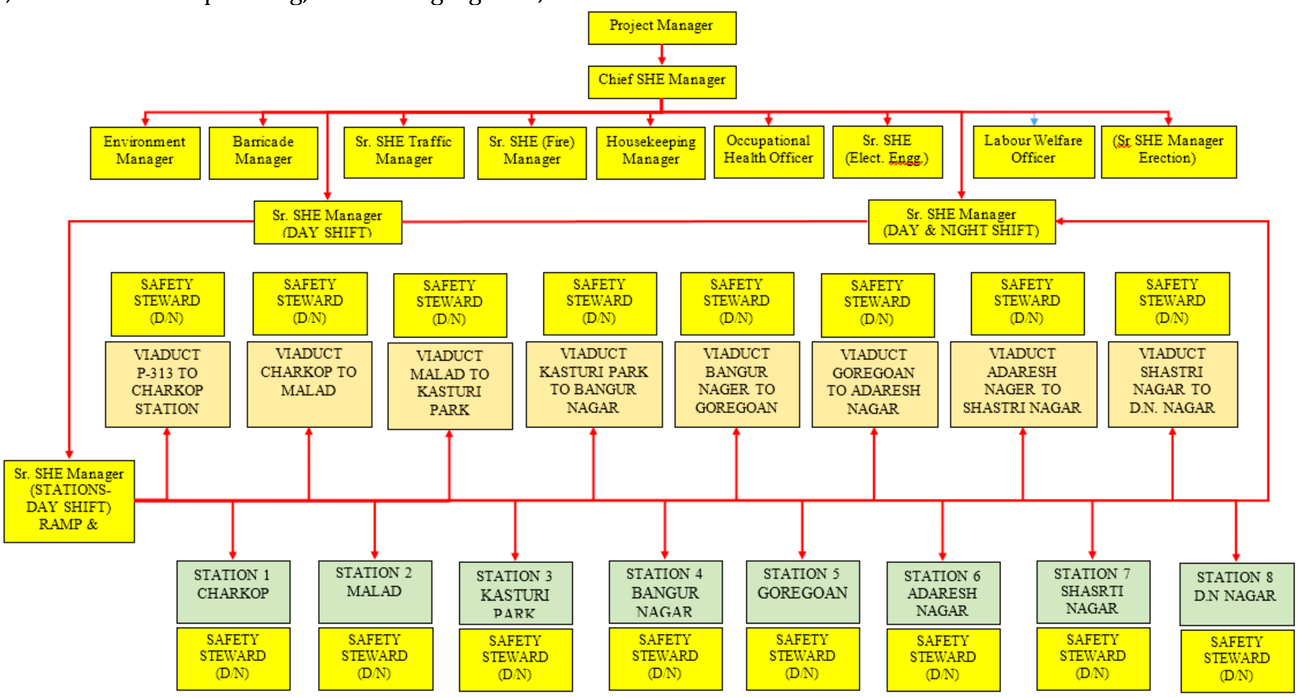

Figure 1: Organizational Chart of metro construction under review

2. METHODOLOGY

The methodology adopted in the research focuses on providing the task specific control measures to minimize or to mitigate the identified hazard during metro construction project. The methodology uses Hazard identification and risk assessment with controls (HIRAC) method to analyse the hazard in different segments of metro construction

Hazard Identification, Risk Assessment and Control is a process that aids in management of occupational and health hazards in the workplace. HIRAC is implemented to maintain safe working environment with modern safety and health legislation. Figure 4.1 shows the steps involved in HIRAC.

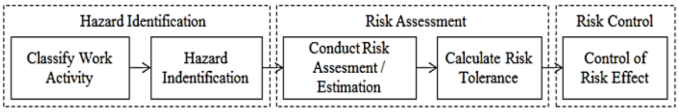

Figure 2: HIRAC steps (Shaleh & Leman, 2016)

1) Hazard identification

Hazard identification is the practice of detecting hazards in the place of work or for a work practice. It is essential to comprehend the nature of hazards for additional comprehension about what hazard identification encompasses. There are numerous different types of hazards and in order to identify it, the association must classify them into few categories comprising physical, biological, chemical and psychosocial hazards which are frequently bring into being in workplaces.

All-inclusive hazard identification might necessitate a lot of work and may turn out to be time intense. Besides, it might be essential to conduct hazard identification frequently to ensure its efficiency. The utmost operative technique is to fragment the workplace into numerous discrete zones for the identification and emphasis the ones having high priority on the basis of hazardous plant, substances, processes or environment.

Only the domain expert having ample Knowledge and who is familiar with the work procedure such as workers, supervisors should provide their experiences and opinion concerning the hazards involved

2) Risk assessment

Risk assessment involves estimation of the extent of risk and determining whether or not risk is acceptable to work on. It is evaluating using the scale of "likelihood" and "consequence" of a specified hazardous event occurring. For high risk tasks, appropriate action must be placed to diminish the risk level that can be accepted as a safe workplace.

In the next stage, the identified hazards are to be listed and ranked into its level of consequences and likelihood. Consequences are defined as the severity of the effect or the degree of harm caused by the risk whereas likelihood is the probability that a risk will occur. Mathematically, the risk level is computed by the multiplication of likelihood (L) and severity (S)

Risk Level = L x S

Table 1: Rating scale Likelihood of occurrence

Likelihood (L)	Example	Rating
Most Likely	The most likely result of the hazard/ event being realized	5
Possible	Has a good chance of occurring and it is not unusual	4
Conceivable	Might be occur at sometimes in future	3
Remote	Has not been known to occur after many after	2
Inconceivable	Is practically impossible and has never occurred	1

Table 2: Rating scale severity of the occurrence

Severity (S)	Example	Rating
Catastrophic	Numerous fatalities, irrecoverable property damage and productivity	5
Fatal	Approximately one single fatality major property damage if hazard is realized	4
Serious	Non-fatal injury, permanent disability	3
Minor	Disabling but not permanent disability	2
Negligible	Minor abrasions, bruises, cuts, first aid type injury	1

The scores of likelihood and severity rating can be used to form the risk matrix where it is positioned in cells equivalent to the appropriate likelihood and severity. Respectively of the risks positioned in the table will tumble under one of the categories, for which unlike colours can be used to signify the priority level.

Table 3: Risk Matrix

Risk matrix		Severity (S)				
		1	2	3	4	5
Probability (P)	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25

The outcome from comparative risk will be rank rendering to the risk matrix score in Table 3. The higher the risk relative score, the further substantial action is needed. High score call for instant action, intermediate score required preparation of controlling the hazard and low risk is deliberated acceptable and tolerable.

Table 4: Action description for risk levels

Index	Description	Action
1-4	Low	Acceptable and further reduction may not be necessary.
5-12	Medium	Planned approach to controlling the hazard and applies temporary measure if required.
15-25	High	Immediate action to control the hazard as detailed in the hierarchy of control.

3) Risk control

The risk control actions were determined based on the hazard and the application of engineering controls, administrative controls, and PPEs. Proper hierarchy of risk control measure should be followed as shown.

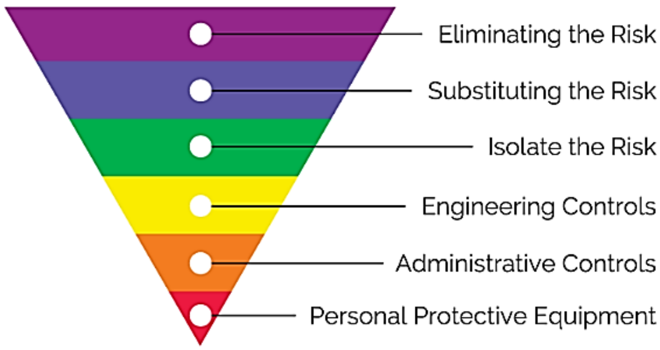

Figure 3: Hierarchy of controls

3. RESULTS

Hazard Identification, Risk Assessment and Control method of assessing hazards in a worksite is a comprehensive and extensive approach aiming to make the workplace safe and healthy. However, due to the comprehensive, cumbersome and laborious nature of the approach, it is not possible to assess each activity or task during the different stages of metro construction. Therefore, in this research the Hazard Identification, Risk Assessment and Control method is applied to three major operations that involves extensive man-machine interaction. The operations under assessment are:

[1] Pile Boring

[2] Concourse Pier Cap Erection

[3] Steel Girder Erection

Figure 4shows the outcome of the assessment of the above three operations where in total 34 hazards where identified in different sub-tasks described in Table 5.1-5.3 on which HIRAC was applied as discussed in the methodology. Table 5.1, Table 5.2 and Table 5.3 shows the different sub-tasks and the identified potential hazards during the operation of Pile Boring, Concourse Pier Cap Erection and Steel Girder Erection respectively according to the discussed methodology for the application of Hazard Identification, Risk Assessment and Control (HIRAC).

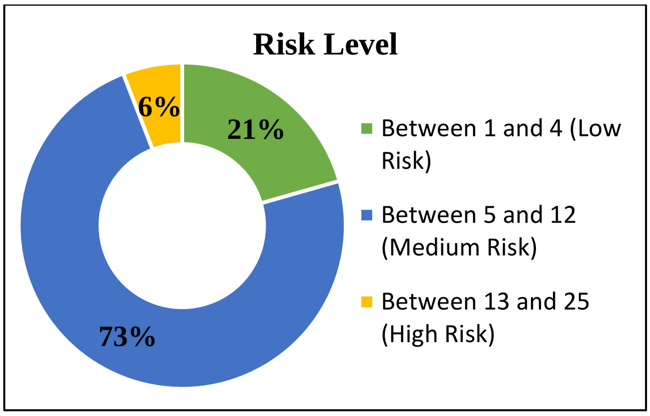

Figure 4: Risk Level distribution

4. CONCLUSIONS

The research covers the assessment of underlying hazards during metro construction which are sited in the center of clogged cities alongside the active roads. These hazards possess very high potential for any mishap or accident with the neighboring buildings, underground covered-up pipelines, pedestrians, road vehicles and to the workers themselves. The approach adopted uses Hazard Identification and Risk Assessment with Controls (HIRAC) and the outcomes from the approach are stated below:

- HIRAC provides a little advantage over the conventional HIRA approach by including the criteria specific control measures providing a holistic and comprehensive approach to safer and healthier working environment.
- The drawback observed while implementing HIRAC was the amount of time, effort and domain experience required of proper implementation. The approach is time consuming and requires subject or domain expertise.
- With the ground implementations of the recommendations from this approach, the risk level of hazardous tasks was easily reduced and brought down to a safer acceptable level.

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Table 5: Identified hazard and their severity, Likelihood and Detectability values

S No.	Task / Activity	Sub-Task	Hazards	(S)	(L)	(D)
1	Steel girder erection	Site Preparation	Settlement of soil / ground	2	1	1
2	Steel girder erection	Loading & Unloading of steel girder member from stacked point on multi axle trailers and from trailer to on ground.	Collapsing of trailer as well as crane due to inadequate capacity or any other external factor.	3	3	3
3	Steel girder erection	Assembly of Steel Girder	Collapsing of crane/Hydra due to inadequate capacity or any other external factor, Toppling of steel girder , Tripping hazard	3	2	4
4	Steel girder erection	Shifting /Transportation of girder	Failure of trailer, Other vehicular hazard.	3	4	4
5	Steel girder erection	Traffic Diversion	Constant movement of traffic will affect the proceeding of work and eventually turn into accident.	3	3	2
6	Steel girder erection	Electrical Management & Illumination	Struck by something, slip, trip fall or Electrocution.	4	3	4
7	Steel girder erection	Crane positioning at erection location.	Toppling of crane. Electrocution. Road side obstruction,	3	2	3
8	Steel girder erection	Lifting of steel girder segments.	Failure of Lifting tools and tackles. Breakdown of crane or toppling of crane, Oil spillage.	4	4	4
9	Steel girder erection	Hot work (Welding/Gas cutting) at height	Electrocution , Falling fireball / molten metal, tripping hazard	4	3	3
10	Steel girder erection	Deck slab	Unprotected leading edges, work platforms and access.	4	3	3
11	Steel girder erection	Working at Height	Unprotected leading edges, work platforms	4	3	3
12	Steel girder erection	Handling of Emergency situation	Failure of machine, slip/trip by person, electrocution, weather condition etc.	1	1	1
13	Concourse pier cap erection	Site Preparation at erection location.	Settlement of soil / ground	2	1	2
14	Concourse pier cap erection	Trestle Erection	Failure of trestle/ trestle members, Nut-bolts, Hydraulic/ mechanical jacks, hand tools/power tools or Fall of person	4	3	2
15	Concourse pier cap erection	Loading of CPC from stacked point on multi axle trailers.	Collapsing of Multy axel trailer as well as crane / Gantry crane due to inadequate capacity or any other external factor.	3	3	3
16	Concourse pier cap erection	Shifting /Transportation of CPC	Failure of Multy axel trailer, Other vehicle hazard.	3	4	3
17	Concourse pier cap erection	Traffic Diversion	Constant movement of traffic will affect the proceeding of work and eventually turn into accident.	3	3	3
18	Concourse pier cap erection	Electrical Management & Illumination	Struck by something, slip, trip fall or Electrocution.	4	3	3
19	Concourse pier cap erection	Crane positioning at erection location.	Toppling of crane. Electrocution. Road side obstruction,	3	2	3
20	Concourse pier cap erection	Lifting of CPC	Failure of Lifting tools and tackles. Breakdown of crane or toppling of crane, Oil spillage.	4	4	4
21	Concourse pier cap erection	Hot work (Welding/Gas cutting) at height	Electrocution , Falling fireball / molten metal, tripping hazard	4	3	3
22	Concourse pier	Concreting work for stitching of	Unprotected leading edges, work platforms and access, failure of	4	3	3

	cap erection	segments	equipment, falling of tools, falling of man etc.			
23	Concourse pier cap erection	Stressing Work	Falling of jacks or tools or related accessories or failure of man lift or scaffolding materials or Spillage of oils or falling of person etc	4	3	2
24	Concourse pier cap erection	Grouting Work	Failure of Grouting machine, falling of slurry on engaged workmen or on ground from height.	3	2	2
25	Concourse pier cap erection	Working at Height	Unprotected leading edges, work platforms	4	3	2
26	Concourse pier cap erection	Handling of Emergency situation	Failure of machine, slip/trip by person, electrocution, weather condition etc.	1	1	1
27	Pile boring	Mobilization of equipment/ machinery, Surface preparation and positioning of Boring RIG	Excavator hit to personal/ vehicle, equipment failure, person injured during machine and equipment movement, machine topples.	4	3	3
28	Pile boring	Drilling by boring Rig & Liner fixing.	Personal injured by auger, rig hit the personal /equipment during swinging, falling hazards	3	2	2
29	Pile boring	Steel Fixing and Cage fabrication	Steel fall on the personal during shifting, cut , electric shock, tripping while cage fabrication or shifting.	2	2	2
30	Pile boring	Cage Lowering and trimme pipe fixing.	Hydra/ crane hit to the personnel, material fall on the personal, damage due to fall, equipment failure, damage to lifting hook.	3	2	3
31	Pile boring	Welding and gas cutting activity for Cage welding	Burn, fire, electrocution	1	1	1
32	Pile boring	Concreting of pile	TM hit to or fall on the personnel, equipment failure, Concrete hopper , trimme hit the personnel	3	2	2
33	Pile boring	Removal of liner and back filling	Hydra, crane and backhoe loader hit to the personnel, material fall on the personnel or damage due to fall/ mishandling, equipment failure, jerk load, damage to lifting hook.	4	3	3
34	Pile boring	Emergency evacuation procedure	Personal injured by vehicle or other reason (slip, trip, fall, illness etc.)	1	1	1