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Assessing Potential Hazards and Carrying Out Risk Assessments in Heavy Construction Projects through the Application of Health and Safety Management Systems

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Abstract:*For any industry to thrive, it must not only focus on production goals but also uphold the highest standards of safety for everyone involved. This requires continuously identifying potential hazards, evaluating the risks linked to them, and reducing those risks to acceptable levels. The construction sector, in particular, is inherently hazardous and poses significant safety challenges for workers. Unsafe site conditions and poor practices often result in accidents that cause injuries, loss of life, property damage, and disruptions to developmental activities. Risk assessment serves as a structured approach to pinpointing and analyzing hazards tied to specific tasks, while also determining the level of risk each hazard presents. Since it is impossible to eliminate all hazards completely, it becomes essential to define and estimate accident risk levels, whether expressed in quantitative or qualitative terms. Because construction sites record a high number of fatalities, the industry is recognized as one of the most hazardous occupations globally. Despite its crucial role, the construction sector is often associated with elevated accident rates and health issues that affect workers, professionals, and even end users. The industry faces considerable safety risks and financial losses as a result. Accurately estimating these risks, however, remains challenging due to the absence of comprehensive quantitative safety databases and the inherent uncertainty in construction projects. Many of the safety risk assessment tools currently used in this field do not always deliver reliable results, as it is difficult to evaluate hazardous events quantitatively. This limitation stems from the lack of detailed safety data, which makes it challenging to determine the likelihood and potential consequences of such incidents.Hazard identification and risk analysis involve recognizing undesirable events that may give rise to hazards, examining the mechanisms through which such events could occur, and estimating the extent, severity, and likelihood of their potential harmful effects. The purpose of this study is to examine current practices in health and safety risk assessment, risk communication, and risk control, while also seeking ways to strengthen the Environmental Health and Safety (EHS) management plan for construction sites. To achieve this, a case study approach was applied, with a construction site selected using convenience sampling. This research further investigates the methods adopted by organizations in India to ensure workplace safety and evaluates how risk assessment can be effectively employed to optimize safety management practices in the construction industry.*

Keywords: Health and Safety Management Systems, Risk Assessment, Hazard Identification, Heavy Construction Projects, Occupational Safety, Construction Risk Management, Safety Compliance, Accident Prevention etc

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I. INTRODUCTION

Project management is the science which applies skills, tools and techniques to fulfil project activities in a way that the expectations and requirements of stakeholders are fulfilled or exceeded. Project risk management is an integral part of the process which aims at identifying the potential risks associated with a project and responding to those risks. It includes activities which aim to maximize the consequences associated with positive events and to minimize the impact of negative events. It is believed generally that risk in an environment is a choice rather than fate, and the inherent uncertainty in the plans can affect the desired outcome of achieving project and business goals [1]. Risk is present in all the activities in a project; it is only the amount which varies from one activity to another.

Variations are inevitable on building and civil engineering projects and may range from small changes having little consequential effects to major revisions, which result in considerable delay (or) disruption to the project [4]. There are a number of reasons for the introduction of changes on construction works including:

- Inadequate briefing from the client
- Inconsistent and late instructions from the client
- Incomplete design
- Lack of meticulous planning at the design stage
- Lack of co-ordination of specialist design work
- Late clarification of complex details

Additionally on civil engineering works there are many cases where changes and new rates are necessary because of the nature of the ground [2]. Furthermore, changes may occur due to the client's desire to incorporate the latest technology into the project which will led to deviations of time and cost of the project which indicate the risk in the project [3]. The current study is focused on concepts of all types of risk management at the construction site of construction work. and will cover the related literature on the topic.

1.1 Concept of Risk Analysis: -

The concept of risk is multi-dimensional. In the context of construction industry, the probability that a definite factor detrimental to the overall project occurs is always present. A lack of predictability related to the consequences of a planning situation and the associated uncertainty of estimated outcomes leads to the consequence that results can either be better than expected or can be worse [5]. In addition to the different definitions of risks, risks can be categorized for different purposes as well. The broad categories of construction risks are external risks and internal risks; while some other categories curtail risks as political, social and safety risk etc.

1. Project Risk
2. Determination of Risk
3. Factors affecting Risk
4. Types of Risks
5. Common sources of risk in construction projects
6. Major processes of Project Risk Management
7. Response to Risk
8. Advantages of Risk Management
9. Limitations of Risk Management

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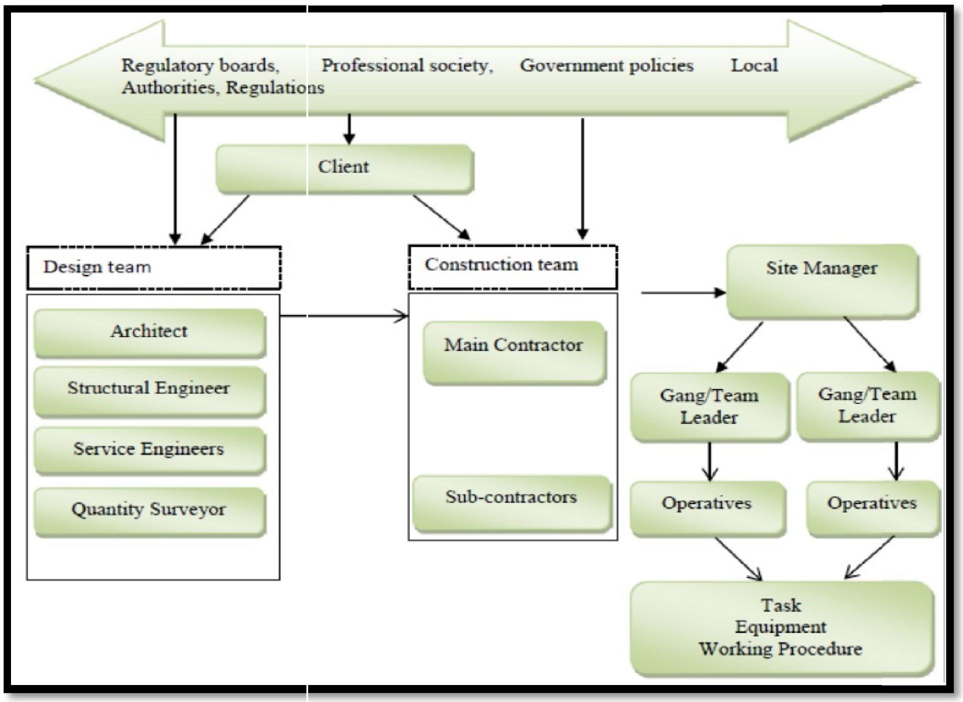

Figure 1.1 Designed Frame of Working

1.2 Definitions of Key Terms: -

The field of risk management is faced with difficulties in defining and agreeing on principles. Risks are dealt with differently across different countries, industries and sectors and fields. Terms, definitions and interpretations are as varied as the number of sources providing them. There are no agreed unified definitions of risk, risk analysis, assessment and management. There are often misconceptions. Different terms, for example "risk analysis" and "risk assessment", are often used interchangeably [8].

1. Health: - Health is the general condition of a person in mind, body and spirit, usually meaning to be free from illness, injury or pain.

2. Safety: - Safety is related to external threats, and the perception of being sheltered from threats. According to the business Dictionary, safety is defined as a relative freedom from danger, risk, or threat of harm, injury, or loss of personnel and/or property, whether caused deliberately or by accident.

3. Hazards: - A hazard is the potential for harm. In practical terms, a hazard is often associated with a condition or activity that, if left uncontrolled, can result in an injury or illness.

4. Risk: - Risk has been traditionally defined as a measure of the probability and severity of adverse effects [9].

Where, S = Scenario leading to hazard P = Probability of occurrence C = Consequence (severity)

5. Accident and Injury: - The terms accident and injury refer to separate phenomena, mutually interrelated as cause and effect (exposure and outcome) [10].

6. Risk Assessments: - The Health and Safety Executive (HSE), defined risk assessment as a process that identifies the hazards associated with particular activities/tasks, evaluates the effects of exposure to these hazards and implements the measure needed to control the risk of injury/ill health to as low a level as possible.

7. Risk Management: - Risk management is an integral component of good management and decision-making at all levels. In construction having a perception of risk management is an integral part of construction management.

8. Risk Communication: - The notion of risk communication refers to a social process by which people become informed about hazards, are influenced to change their behaviour and are enabled to participate in decision- making about risk issues [11].

9. Risk Control: - Risk control is a technique that utilizes findings from risk assessments (identifying potential risk factors in a firm's operations, such as technical and non-technical aspects of the business, financial policies, and other policies that may impact the well-being of the firm), and implementing changes to reduce risk in these areas.

II. LITERATURE REVIEW

Akintoye et.al [12] The paper describes, based on a questionnaire survey of general contractors and project management practices, the construction industry's perception of risk associated with its activities and the extent to which the industry uses risk analysis and management techniques. It concludes that risk management is essential to construction activities in minimizing losses and enhancing profitability.

Bing &Tiong et.al [13]The current Asian financial crisis has put the role of risk management in the construction business into focus. For firms engaging in the international construction business, one of the most effective means of mitigating financial risks is through a joint venture (JV) with a local partner. Daniel et.al [14]This paper discusses the core issues of global risk factors modelling, assessment and management. The research reported upon forms part of a larger study that aims to develop a fuzzy decision framework for contractors to handle global risk factors affecting construction cost performance at a project level. [15] Major global risk factors affecting cost performance were identified through an extensive literature review and preliminary discussions with construction contractors.

Hastak M. et.al [16] This paper presents a risk assessment model for international construction projects. The International Construction Risk Assessment Model (ICRAM-1) assists the user in evaluating the potential risk involved in expanding operations in an international market by analysing risk at the macro (or country environment), market, and project levels.

Akintoye et.al [17] The paper describes, on the basis of a questionnaire survey of general contractors and project management practices, [18] the construction industry's perception of risk associated with its activities and the extent to which the industry uses risk analysis and management techniques.

Emmanuel Eze et.al [19]The complex networks of activities of construction projects have made the construction environment unfriendly and unsafe for the construction tradespeople.

III. PROBLEM IDENTIFICATION AND SYSTEM DOMAIN

Safety is a basic physical and psychological need of human beings. Every day some 950 people die and over 720,000 workers get hurt because of occupational accidents. Annually, over 48,000 workers die because of occupationalaccidents in India and there are almost 37 million occupational accidents which causes at least 4 days' absences from work [25]. In terms of economics, the International Labour Organization (ILO) has estimated that the total costs of occupational accidents and work-related diseases are 4% of the gross national product (GNP). The total GNP of the world was approximately 84.54 trillion USD in 2020 (World Bank 2020) which means that worldwide the annual cost of work-related injuries and diseases is approximately 3.3 trillion USD (0.04x 84.54).

3.1 Identification of Problems at Constructions: -

Construction sites are among the hazardous places where injuries and fatalities of workers commonly happen. The EHS issues are giving a bad image to the socio-economic importance of the construction industry. The cruel fact is that most of the accidents are unnecessary which could have been protected if the principles of OSH had been implemented at workplaces.

In the absence of properly compiled data, the scale of EHS problems may not be well understood. If the causes leading to occupational accidents and injuries at construction sites are not identified and awareness of EHS issues is not created to the stakeholders of the construction sector, the problems will continue to significantly affect the construction sector as well as the socio economy of the country.

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This study therefore attempts to address such issues and hence it is expected to reduce consequential effect of occupational accidents, injuries and fatalities.

Table 1: Regional HSE Score Card

S.No	Detail	Values
1.	Total SafeManHours – December-2021	22,19,496
2.	CumulativeSafeManHours–FY#2021-22	24,96,45,304
3.	No.ofReportableInjuries–FY#2021-22	6
4.	Nos.ofMinorInjuries– FY#2021-22	11
5.	CumulativeIncidentRate	0.11
6.	CumulativeFrequency Rate	0.04
7.	CumulativeSeverity Rate	240.37
8.	HSEWalkconducted- - Feb-2021	100%
9.	HSECommitteeMeetingsConducted- Feb-2021	100%
10.	HSETrainingConducted, TrainingManHours- Feb-2021	10042
11.	Total FirstAid Report- Feb-2021	74
12.	TotalNearMiss –Feb-2021	13
13.	UnsafeWorkStoppageNotificationsIssued- Feb-2021	16
14.	WarringLetters/MemosissuedatProjectLevel– Feb-2021	48
15.	ProjectsAuditedbyRegionalHSETeam&Auditreportsissued-Feb-2021	8

3.2 Reasons behind Past accidents: -

1. Electrical Activity
2. Hot Work
3. Material Handling
4. Scaffolding
5. Shuttering
6. Height Work
7. Concreting
8. Vehicle Movement
9. Sudden Breakdown maintenance equipment.
10. Welding & Cutting
11. Use of Lifting Equipment
12. Painting & coating Work
13. Concrete pump
14. Ladder
15. Bar bending & Cutting
16. Storage of Flammable material
17. Tower Crane

IV. RESEARCH METHODOLOGY

This chapter presents the research strategy used in this study. It reviews the basic research approaches available, which include the quantitative, qualitative and mixed methods approach.

Thereafter the chapter discusses the method opted in this study and its justification. The research design is illustrated followed by a discussion of case selection and the methods used for data collection.

• Brain storming:
• Delphi technique:
• Interview /expert opinion:

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- Past experience:
- Check lists:
- Influence diagram:
- Flow chart:
- Cause-and-effect diagrams:

This system classifies the trades by the principal skills inherent in the trade below: -

Table 1 Hazards Distribution [34]

S.No	Occupation	Typesof HAZARDS
1.	Brick masons	Cement dermatitis, awkward postures, heavyloads
2.	Stonemasons	Cement dermatitis, awkward postures, heavyloads
3.	Hard tile setters	Vapour from bonding agents, dermatitis,awkward postures
4.	Carpenters	Wood dust, heavy loads, repetitive motion
5.	Drywall installers	Plaster dust, walking on stilts, heavy loads,awkward postures
6.	Electricians	Heavy metals in solder fumes, awkwardposture, heavy loads
7.	Electrical power installers and repairers	Heavy metals in solder fumes, heavy loads
8.	Painters	Solvent vapours, toxic metals in pigments, paintadditives
9.	Plasterers	Dermatitis, awkward postures
10.	Plumbers	Lead fumes and particles, welding fumes
11.	Pipefitters	Lead fumes and particles, welding fumes
12.	Steamfitters	Welding fumes
13.	Carpet layers	Knee trauma, awkward postures, glue and glue vapour
14.	Soft tile installers	Bonding agents
15.	Concrete and terrazzo finishers	Awkward postures
16.	Glaziers	Awkward postures
17.	Insulation workers	Synthetic fibres, awkward postures
18.	Paving, surfacing and tamping equipment operators	Asphalt emissions, gasoline and diesel engine exhaust, heat
19.	Rail- and track-laying equipment operators	Silica dust, heat
20.	Roofers	Roofing tar, heat, working at heights
21.	Sheet metal duct installers	Awkward postures, heavy loads, noise
22.	Structural metal installers	Awkward postures, heavy loads, working at heights
23.	Welders	Welding emissions
24.	Solders	Metal fumes, lead, cadmium
25.	Drillers, earth, rock	Silica dust, whole-body vibration, noise
26.	Air hammer operators	Noise, whole-body vibration, silica dust
27.	Pile driving operators	Noise, whole-body vibration
28.	Hoist and winch operators	Noise, lubricating oil
29.	Crane and tower operators	Stress, isolation
30.	Excavating and loading machine operators	Silica dust, histoplasmosis, whole-body vibration, heat stress, noise

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4.1 Methodological detail

The research work started with problem identification. The problem identification is done through literature review and discussions with professionals in the construction industry. The nature of the research is explorative, and the research methodology comprises three stages as stipulated below.

1. Stage 1: Identifying the status of EHS management in the construction industry by conducting literature review and discussions with professionals in the industry.
2. Stage 2: Then analysis and discussion are conducted to draw conclusions
3. Stage 3: Designing the Risk assessment of different project sites and updating EHS plan for a construction site based on literature review and discussions and forward recommendations based on the findings of the study and the reviewed literatures.

In the construction industry, risk can be defined in relation to occupational accidents leading to fatal incidents. Risk [29] is intrinsic in all project undertakings, as it can never be fully eliminated, although it can be effectively managed to mitigate the impacts on the achievement of the objective of the project. Other definitions of risk are available in the literature, for example, "the traditional view of risk is negative, representing loss, hazard, harm and adverse consequences" and "the underlying condition that can generate a possible risk event at some time forward from the point of decision-making". [38] state that the impact of risk can be measured as the probability of a specific unwanted event and its unwanted consequences or loss:

Where, RM = Risk magnitude; RL = Risk likelihood; RS = Risk severity

V. MATHEMATICAL MODEL AND REPORT

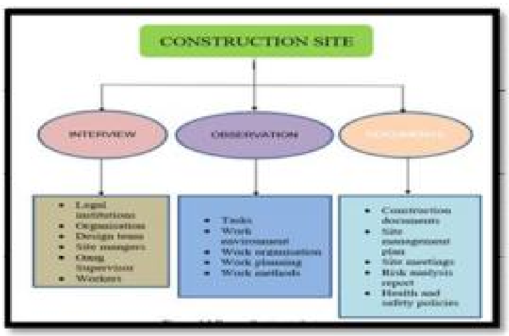

Figure 3 Data Collection Techniques

Project work has been done in four steps. First attempt is to understand every step for construction of bridge i.e., survey, design, planning, resource assembling, pilling, pile cap, cofferdam work, pier and pier cap and erection works. Secondstep is to develop a 4x4 matrix for risk analysis as per IMS manual, then EHS Risk assessment done by matrix method for every activity. Then gap analysis is done by Data collection, data analysis, Employee survey, EHS walk down, evaluate findings and suggest improvement.

Table 2 Data Collection Matrix

S. No	System	Variable	Method	Data
1.	Institutional system	Regulations	Interviews, documentary review	Legal practices in health and safety risk management.
		Institutional Structure	Interview	Power relations: management,
		Control mechanism	Interviews, documentary review	Control methods and enforcement technique.
2.	Organisation system	Management style	Interview	Involvement, resource allocation
		Structure	Interviews, documentary review	Organisation structure, power relation
		Company policy	documentary review	Health and safety policy

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		Communication	Interview	Methods/ tool and Communication channel
3.	Individual system at construction sites	Education, Experience	Interview	Demographic information
		Perception	Interview	Feeling about the risk
		Responsibility	Interview and observation	Different roles of individuals regarding risk assessment, communication and control
4.	Work Environment	Working tools/methods Work teams Working Procedure Physical space	Observation	Methods of working Team cooperation Working procedures Site space.

The chapter discussed the approaches to research, namely, the quantitative method. This study opted to use the case study method to achieve its objective. The justification for using the case study to gather empirical data was discussed. The research design was also shown to have part by part comprising an extensive literature review and the conducting of a pilot study and part being the main fieldwork, whereby each case would be analysed, there would be a cross-data analysis and, last but not least, the conclusion would be provided. The next chapter discuss the empirical finding from study as their results.

VI. RESULTS AND DISCUSSIONS

This chapter presents the nature of health and safety risk on construction sites and provides an overview of how site managers, supervisors and workers perceive those risks. The first part of this chapter provides the results from the interviews held with five site managers on the types and sources of accidents and ill-health problem on construction sites. The second part provides the results from the questionnaire survey of site managers, gang supervisors and workers on how they perceive the health and safety hazards identified by the interview survey.

Table 3 Health and safety hazard consequences as ranked by site managers [50]

S. No	Type of health and safety hazards consequences	Rank
1.	Falling from height	8
2.	Hit by falling object, trips and fall	7
3.	Back pain, muscular pain, due to manual handling	6
4.	Health problem caused by chemicals	5
5.	Health problem caused by dust	5
6.	Health problem caused noise	5
7.	Crushed moving equipment, cuts by equipment and hand-led tools	4
8.	Health problem caused by too long bending and twisting	4
9.	Injury from fire and other disaster	3
10.	Covered by earthwork during excavation of basement and trenches	2
11.	Bullying and stress	1

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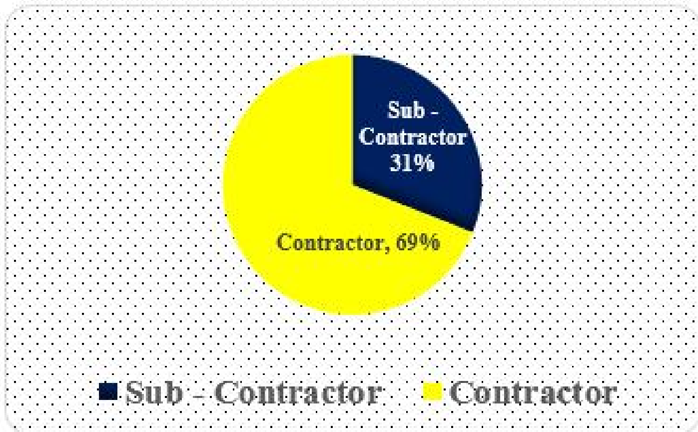

Figure 4 Employers on the construction sites

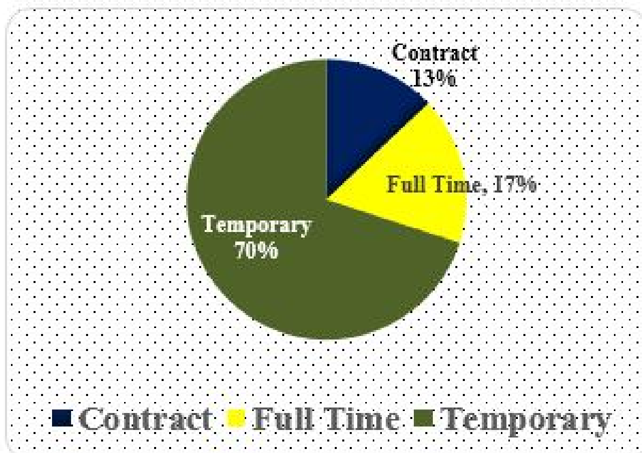

Figure 5 Nature of employment on construction sites

6.1 Risk Perception: -

Site managers, gang supervisors and workers were asked to indicate qualitatively the probability of health and safety problems occurring when working in a hazardous situation. The Likert scale was used where 1 = very likely to occur, 2 likely to occur, 3= moderate, 4= not likely to occur, and 5, Not likely to occur at all (never). The results are as indicated in Figures 6 and 7.

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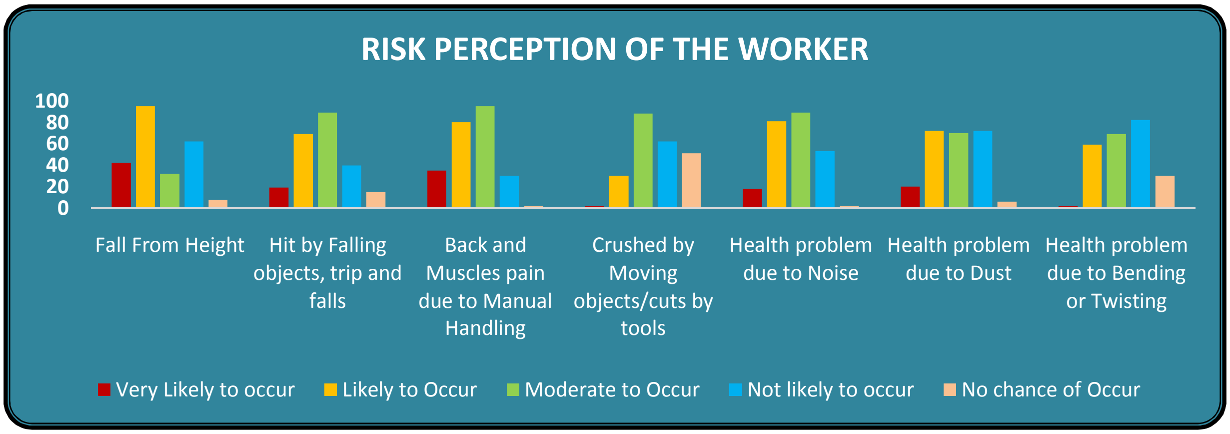

Figure 6 Risk perception of the worker

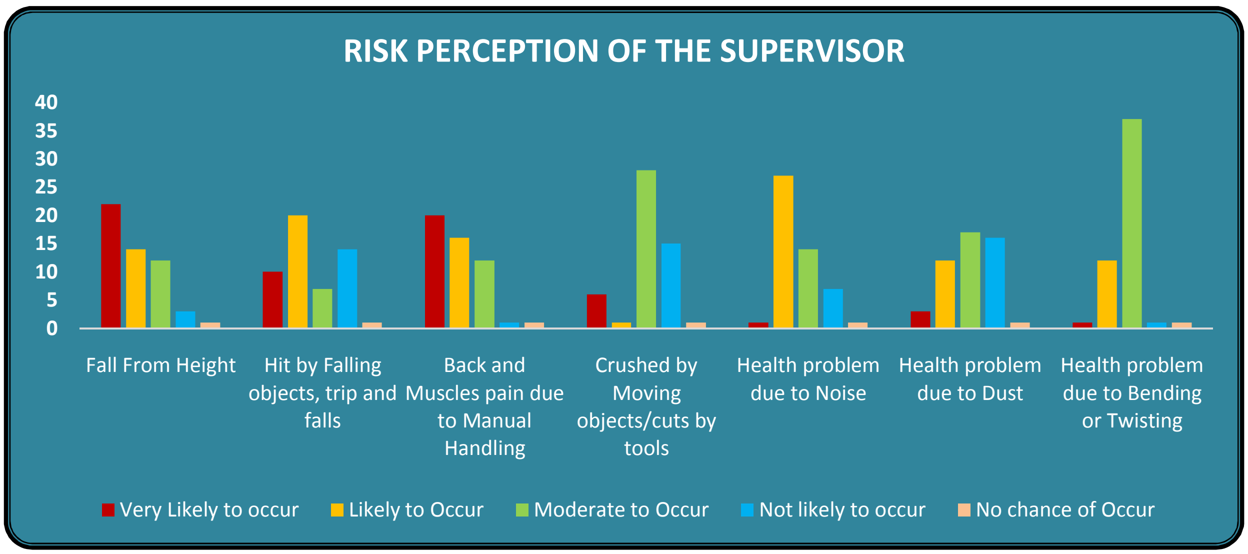

Figure 7 Risk perception of the Supervisor

Hazard Consequences Categorization: -

This categorization is performed so as to determine which hazard consequence is perceived as higher by both group supervisors and workers. In hazard categorization, hazard consequence was calculated according to the number of respondents who indicated that the probability of occurrence was very likely to occur and likely to occur. The results have been grouped into categories. Category A indicates hazards consequence highlighted by over 150 respondents.

Category B contains hazard consequences highlighted by 100-149 respondents. Category C represents hazards consequences mentioned by 50-99 respondents, and Category D contains hazard consequences mentioned by under 50 respondents. The results are indicated in Table below.

Table 4 Hazards consequences category as perceived by workers and supervisors

S. NO	HAZARD CONSEQUENCES	RESPONDENT	CATEGORY
1.	Fall From Height	171	A
2.	Hit by Falling objects, trip and falls	152	A

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3.	Back and Muscles pain due to Manual Handling	126	B
4.	Crushed by Moving objects/cuts by tools	118	B
5.	Health problem due to Noise	107	B
6.	Health problem due to Dust	71	C
7.	Health problem due to Bending or Twisting	36	D

Key to the hazard consequence categories
A: Highest hazard consequence category
B: Second hazard consequence category
C: Third hazard consequence category
D: Fourth hazard consequence category

Table 7.5.1 RISK ASSESSMENT

DETERMINING RISK LIKELIHOOD – GUIDANCE CRITERIA		
Likelihood	Weightage	Criteria
Unlikely	1	It is un heard in the industry
Likely	2	It has rarely occurred in other construction companies
Highly Unlikely	3	It has occurred in other construction company
Very Likely	4	It has occurred in other project sites of the company
Certain	5	It has occurred several times at the site location in a year

Table 7.5.2 RISK ASSESSMENT

DETERMINING RISK SEVERITY LEVEL - GUIDANCE CRITERIA			
Severity Descriptions (The highest category shall always be used)			
Value	Result of Hazard to Personal		Severity of the Environmental Impact
	Safety	Health	
5	Single or Multiple Fatality	Terminal Illness	Massive effect
4	Serious injury requiring hospitalization	Unemployed due to illness	Major effect
3	Lost Time injury	Intense health effect	Localized effect
2	Injury requiring medical treatment but no Lost Time	Minor health effect	Minor effect
1	First Treatment only	Slight health effect	Slight effect

Table 7.7 Definitions of Level of Work

RISK LEVEL	ACTION AND TIME SCALE	CATEGORY
TRIVIAL TOLERABLE MODERATE	Continue with the current activity. Monitoring is required to ensure that the controls are effectively maintained	Acceptable (Low Risk)
SUBSTANTIAL	Urgent action is required including engineering/operational controls/administrative controls/PPE /Signages/Training/Behavioural Monitoring	Not Acceptable (Medium Risk)
INTOLERABLE	Immediate action should be taken. Work should not be started or continued until the impact / risk has been reduced	Not Acceptable (High Risk)

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Table 5 RISK PRIORITY INDICATOR

Severity / Likelihood	Insignificant (1)	Slightly Harmful (2)	Harmful (3)	Very Harmful (4)	Extremely Harmful (5)
Highly Unlikely (1)	TRIVIAL (1)	TRIVIAL (2)	TOLERABLE (3)	TOLERABLE (4)	MODERATE (5)
UNLIKEL Y (2)	TRIVIAL (2)	TOLERABL E (4)	MODERATE (6)	MODERATE (8)	SUBSTANTI AL (10)
LIKELY (3)	TOLERABLE (3)	MODERAT E (6)	MODERATE (9)	SUBSTANTIA L (12)	SUBSTANTI AL (15)
VERY LIKELY (4)	TOLERABLE (3)	MODERAT E (8)	SUBSTANTIAL (12)	SUBSTANTIA L (16)	INTOLERAB LE (20)
CERTAIN (5)	MODERATE (5)	SUBSTANTI AL (10)	SUBSTANTIAL (15)	INTOLERAB LE (20)	INTOLERAB LE (25)

The results presented above provided an outline of the nature of health and safety risks on construction sites. The main health and safety hazards include working at a height, falling objects, manual handling hazards, noise, dust and bending and twisting and equipment. Workers and supervisors were asked to indicate their perception of identified hazards based on the probability of occurrence of the hazard consequences. Among these hazards' consequences, falling from a height and muscle and back pain due to manual handling were perceived to be highly likely by workers and supervisors, while crushed by a moving object and health problem due to too much bending and twisting were perceived to be less likely.

VII. CONCLUSION AND RECOMMENDATION

This study aimed to ascertain the current practice of health and safety risk management on construction sites, focusing on risk assessment, risk communication and risk control. In pursuing this objective, the case study strategy was adopted, with a holistic view of health and safety risk assessment, risk communication and risk control on construction sites.

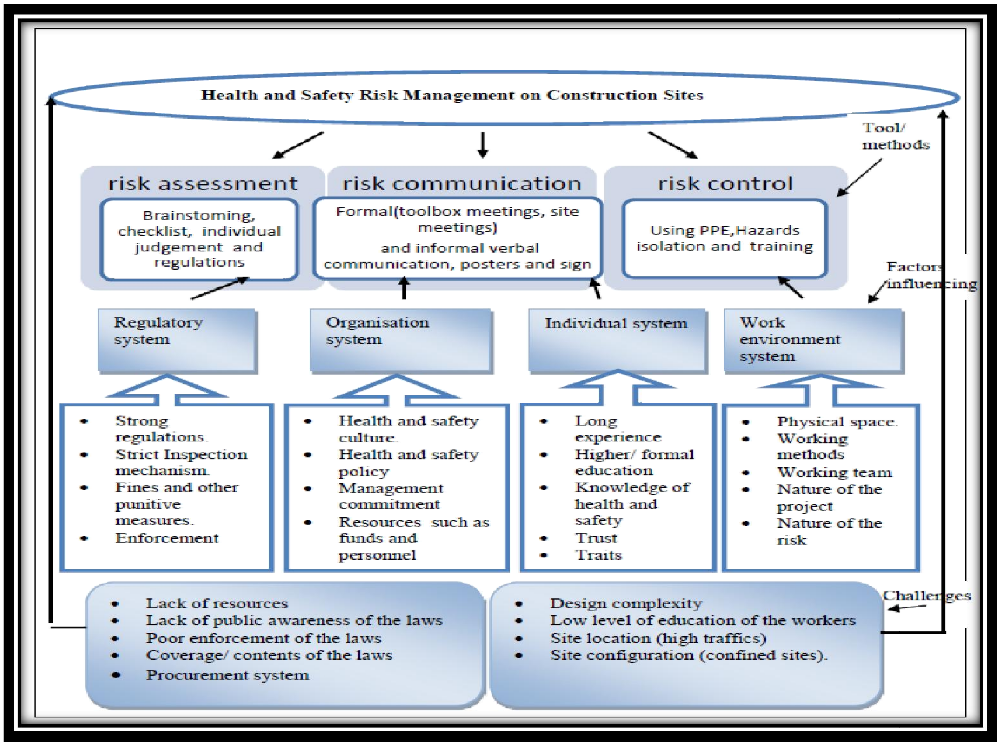
The study revealed that the responsibility for construction site health and safety lies with the main contractor, resulting in many designers, consultants and clients absolving themselves from responsibility if accidents occur on the site. The active participation of clients and design teams in the built environment in health and safety matters is yet to be realised. Meanwhile an appropriate procurement practice that promotes the adoption of good health and safety risk management is an issue.

The study also revealed that no systematic methods were used, but risk was assessed by brainstorming, checklists and health and safety regulations. Judgement of risk was based on individual judgement assisted by experience, educational background and knowledge of health and safety regulations. Working at height and manual handling observed to be most critical hazards in construction sites.

Based on methods used to communicate risk at construction sites, it was revealed that toolbox meetings, site meetings, posters and informal verbal communication are used to communicate risk. It was also revealed that safety committees and gang supervisors play a major role in communicating health and safety risks. However, the issue of power relations and conflicts was observed when there is a clear separation between health and safety communication and quality and productivity. The study also reveals that PPE is the main item used for risk control.

Risk Control Methods

Figure 8.1 Health and safety risk management at construction sites



RECOMMENDATIONS: -

- Implication for Policy, Regulatory System and Industry
- Implication for the Organisations
- Implication for the Professionals concerned with Project Management

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