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Fall Protection Systems on Roofing Sheet and Structural Works

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ABSTRACT: Working at height during sheet roofing and structural roof installation is one of the most hazardous activities in the construction and fabrication industry. Falls from roofs are a leading cause of severe injuries and fatalities due to inadequate protection systems, improper installation practices, lack of training, and unsafe access methods. This study evaluates the effectiveness of fall protection systems used in both sheet roof and structural roof environments, comparing their safety performance, challenges, and compliance with occupational safety standards. Data were collected through field observations, safety audits, interviews with workers and supervisors, and assessment of existing fall protection equipment at multiple industrial and commercial project sites. The findings show that the majority of fall incidents occur due to poor anchorage selection, absence of guardrails, improper scaffolding, damaged lifelines, insufficient personal protective equipment (PPE), and unsafe movement on fragile sheet roofs. Structural roof works further pose hazards such as gaps between members, unprotected edges, unstable platforms, and weather-induced slip hazards. The study concludes that a combination of engineering controls, administrative controls, and PPE significantly enhances worker safety. Systems such as horizontal lifelines, anchor points, safety nets, full-body harnesses, walkway platforms, and edge protection barriers proved effective when implemented correctly. Recommendations include mandatory roof-work training, strict enforcement of safety protocols, improved supervision, and use of advanced fall arrest systems to reduce risks in roof construction activities.

KEYWORDS: Fall Protection Systems, Sheet Roof Safety, Structural Work Hazards, Personal Fall Arrest System (PFAS), Safety Compliance & Regulations, Risk Assessment & Control Measures

I. INTRODUCTION

Roofing sheet installation and structural steel works are among the most hazardous activities in the construction industry due to extensive operations at elevated heights, sloped surfaces, and narrow working platforms. Workers are exposed to a high risk of falls from roofs, edges, openings, fragile sheet areas, and structural members such as rafters, purlins, and beams. Fall accidents remain a leading cause of fatal and non-fatal injuries on construction sites, often resulting from inadequate safety measures, poor planning, lack of training, or failure to use appropriate fall protection systems. Effective implementation of guardrails, lifelines, safety nets, personal fall arrest systems, and proper access arrangements can significantly reduce accident severity and enhance worker safety. Therefore, this study focuses on evaluating existing fall protection practices, identifying safety gaps, and proposing practical improvements to ensure safe working conditions on roofing sheet and structural works, aligning with sustainable development and decent work principles.

Despite the availability of nationally and internationally recognized safety standards, roof-related falls continue to occur frequently in the construction industry due to several persistent shortcomings. One of the primary causes is the inadequate implementation of fall protection systems, where proper anchorage points, lifelines, guardrails, and safety nets are either absent, incorrectly installed, or poorly maintained. Many workers rely solely on basic personal protective equipment without the support of engineered fall prevention measures, significantly increasing risk. Improper work practices, such as walking directly on fragile sheets, using makeshift access methods, carrying materials while climbing, or bypassing harnesses due to discomfort or time pressure, further elevate the hazard. In addition, inadequate training leaves workers unaware of safe roof-walking techniques, load distribution principles, and correct PPE usage.

Insufficient monitoring and supervision play a major role in allowing unsafe practices to go unchecked. Supervisors may be overwhelmed by multiple tasks, lack specialized knowledge in fall protection, or fail to enforce critical safety protocols consistently. Consequently, essential procedures such as pre-work inspections, permit systems, hazard identification, and tool-box meetings are often neglected. Poor communication between workers, riggers, and supervisors can also result in misunderstandings that lead to dangerous actions at height. External factors such as weather conditions and rushed project timelines further compound the problem.

Ultimately, although safety standards exist, their effectiveness depends on strict implementation, continuous training, and proactive supervision. Without these, roof-related fall risks remain high, highlighting the urgent need for stronger safety culture, accountability, and adherence to fall protection requirements at all construction sites.

II. LITERATURE REVIEW

The primary objective of this study is to comprehensively examine the fall protection systems currently used in both sheet roof and structural roof work, focusing on their design, installation, and practical effectiveness in real construction environments. Roof works particularly those involving metal sheets, PEB structures, and steel framing pose unique challenges due to varying heights, surface conditions, and structural configurations. Therefore, this study aims to identify the major hazards associated with different roof types, including fragile sheet surfaces, open edges, gaps between steel members, inadequate access systems, weather-induced risks, and improper use of PPE. By conducting site assessments, equipment inspections, and worker interviews, the study evaluates the extent to which existing fall protection equipment and work practices comply with established safety standards and regulatory requirements. Compliance is analyzed in terms of correct use of harnesses, anchorage points, lifelines, guardrails, walkway boards, and safety nets, along with the adequacy of worker training and supervision. Based on observed gaps, deficiencies, and risk patterns, the study further seeks to develop practical and improved safety strategies aimed at reducing fall hazards in roof construction. These recommendations include implementation of engineered controls, strengthening of administrative procedures such as lift plans and work permits, enhanced PPE management, adoption of advanced fall arrest technologies, and the promotion of a stronger safety culture among workers and supervisors. Collectively, these objectives guide the study toward strengthening protection measures and ensuring safer roof work practices across the construction industry.

This study focuses on various types of roofing systems commonly used in industrial and commercial construction projects, including sheet roofing, metal deck roofing, and structural steel roof installation. Sheet roofing typically involves lightweight metal or composite panels that are prone to fragility, requiring careful handling and specialized fall protection measures to ensure worker safety. Metal deck roofing, often used in industrial warehouses and commercial buildings, presents challenges due to its elevated surfaces, potential gaps between decking panels, and the need for secure anchorage for safety harnesses. Structural steel roof installation involves assembling trusses, beams, and purlins at significant heights, where workers are exposed to open edges, wide spans, and complex geometries, making fall protection a critical aspect of the work. The study also emphasizes access systems such as ladders, scaffolds, stair towers, and temporary platforms, which serve as the primary means for workers to safely reach and maneuver across roof surfaces. In addition, it examines various fall protection solutions including personal protective equipment (PPE) like full-body harnesses, lanyards, and shock absorbers; engineered controls such as guardrails, horizontal lifelines, and anchor points; and safety nets or walkway platforms designed to mitigate the risk of falls. By analyzing these roofing types and associated fall protection methods, the study aims to identify gaps, assess compliance with safety standards, and recommend effective strategies to enhance worker safety in industrial and commercial roof construction projects.

This chapter describes the materials, tools, equipment, data sources, and the systematic methodology adopted to study fall protection systems used in roofing sheet and structural work operations. The research methodology includes the collection of site-based observational data, safety audits, questionnaires, interviews, accident data analysis, and literature review. The approach focuses on understanding existing safety practices, identifying major risk factors, evaluating the effectiveness of fall protection systems, and proposing practical improvements based on engineering and management principles.

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III. RESEARCH METHODOLOGY

The materials used for the research include safety equipment specifications, fall protection system components, structured survey forms, checklists, site inspection instruments, and reference standards. Data was collected from industrial construction sites where roofing sheet installation and structural erection work were actively ongoing. Personal protective equipment (PPE) samples and fall arrest system components were evaluated to assess compliance with standards such as OSHA, ANSI, BIS, and ISO regulations.

PPE items examined for this study include full-body harnesses, helmets with chin straps, safety shoes with steel toes, safety lanyards, shock absorbers, carabiners, rope grabs, retractable fall arresters, gloves, and reflective jackets. Technical specifications such as load capacity, material strength, and certification labels were evaluated. The compatibility between harnesses and connecting devices was assessed to understand proper alignment with personal fall arrest system requirements.

The study included the inspection and evaluation of horizontal lifelines, vertical lifelines, anchor points, anchor posts, clamping anchors, and beam clamps used in structural frameworks. Engineered anchor systems used in PEB installations were checked for strength requirements, spacing limitations, installation procedures, and certification compliance. The load-bearing capability of anchorage was Several methods were used to gather data and information relevant to fall hazards and safety performance in roofing and structural works. The methodology includes both qualitative and quantitative research approaches to ensure realistic representation of site conditions.

Direct observation and inspection were conducted on selected industrial construction sites to identify fall hazard zones and evaluate fall protection systems in use. Audits included visual inspection of ladder access, roof openings, fragile sheet areas, guardrail arrangements, lifeline installations, and compliance with safe operating procedures. Photographic evidence and safety audit checklists were used for documentation and comparison.

Structured questionnaires were provided to site supervisors, engineers, safety officers, and workers involved in roofing sheet and structural works. Questions focused on worker experience, PPE usage habits, awareness of fall protection systems, accident history, training received, risk perception, and safety culture attitudes. Interviews with EHS personnel provided expert insights on policy implementation issues and improvement strategies.

Accident reports from construction companies, government databases, and research publications were analyzed to assess the frequency, causes, and severity of fall-related accidents. Statistical tools were used to compare root causes such as equipment failure, poor supervision, worker negligence, improper anchorage, and environmental factors like rain or wind.

The study adopted a systematic process to assess the performance of fall protection systems and their effectiveness in preventing falls on construction sites.

Different fall protection systems including guardrails, safety nets, horizontal lifelines, vertical lifelines, and PFAS were evaluated based on criteria such as ease of installation, worker mobility, safety effectiveness, costs, and compliance with standards. Comparative analysis was performed to identify the most suitable solutions for different roof types such as slope roofs, PEB structures, fragile roof areas, and sheet roofing conditions.

A structured risk assessment process based on Job Safety Analysis (JSA) and Hazard Identification and Risk Assessment (HIRA) techniques was implemented. Each task involved in roofing and structural work was analyzed for potential hazards, probability of occurrence, and severity of consequences. Risk ranking was carried out to prioritize critical hazard areas requiring urgent controls.

Data Interpretation and Validation

Collected data was analyzed and cross-verified with safety standards and expert findings. Validation was performed by comparing site observations with questionnaire responses and accident statistics. The results were finalized based on convergence between field evidence and regulatory expectations.

This chapter outlined the materials, equipment, and systematic research process adopted for evaluating fall protection systems for roofing sheet and structural works. The methods provide a strong foundation for analyzing safety gaps and proposing engineering and management improvements.

IV. RESULT AND DISCUSSION

This chapter explains the experimental setup and step-by-step procedures adopted to analyze the performance, suitability, and effectiveness of fall protection systems used in roofing sheet and structural works. The experimental process consists of selecting real construction sites, identifying hazard zones, installing fall protection equipment under controlled conditions, evaluating their performance, and recording observational and measurement data for analysis. The procedure also includes testing anchorage systems, evaluating worker mobility and comfort, and conducting simulated fall arrest demonstrations to understand the functional characteristics of various safety systems. The experiment focuses on comparing passive and active fall protection systems in terms of safety reliability, installation practicality, and compliance with regulatory standard.

EXPERIMENTAL SETUP

The experimental setup was designed to replicate actual working conditions encountered in roofing sheet installation and structural steel erection. The setup included a selected industrial project site comprising a steel structural framework with purlins, rafters, and a sloped roof surface. Designated fall hazard areas such as roof edges, sheet joint locations, openings, and walk path zones were identified and marked. Temporary work platforms and scaffold access points were installed to observe worker movement and fall exposure risk. Various fall protection systems including full-body harnesses, lanyards, shock absorbers, safety nets, guardrails, and horizontal lifelines were installed and tested for functionality.

Test Locations and Environment

The experiment was conducted in working areas involving different roof levels with varying slopes ranging from 10° to 30°. Environmental conditions such as wind speed, surface slipperiness, weather exposure, and space constraints were taken into consideration during testing to replicate realistic construction challenges. Safety signage and barricades were provided to ensure controlled experimental conditions.

Tools and Measuring Instruments Used

Instrumentation used in the testing phase included load measuring gauges, rope tension meters, measuring tapes, safety audit checklists, strength testing equipment, and fall simulation dummies for controlled drop testing. Video cameras and digital monitoring devices were used to record system performance and worker movement patterns for later analysis and comparison.

V. PROCEDURE FOR EXPERIMENTAL TESTING

The experiment was carried out following systematic and standardized procedures to ensure consistent and reliable data collection.

Installation of Fall Protection Equipment

Fall protection systems were installed on designated roof structural members following manufacturer guidelines and safety standard requirements. Horizontal lifelines were anchored at both ends of the steel framework using beam clamps capable of withstanding required load capacities. Guardrails were fixed along the open roof perimeter with toe boards to prevent slipping tools. Safety nets were installed below working levels to create a secondary level of protection.

Inspection and Verification of Components

Each safety component was visually inspected for wear, certification labels, stitching condition, carabiner locking, and anchor integrity. Anchorage systems were load-tested statically to ensure compliance with minimum strength requirements. Harness fitment and compatibility with lanyards and connectors were checked using standardized PPE inspection forms.

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Simulated Fall Testing

Controlled test drops were conducted using a test dummy weighing approximately 85 kg, representing an average worker. The dummy was suspended using a fall arrest lanyard and dropped from predetermined heights to measure system response, shock absorption capacity, and arrest distance. The oscillation range, body clearance requirements, and swing fall effects were analysed to determine practicality and safety margins.

Worker Mobility and Accessibility Assessment

Trained workers were asked to perform mock installation tasks such as sheet alignment, bolt fastening, rivet fixing, and tool handling while connected to lifelines. Observations were recorded regarding ease of movement, risk of tripping, system comfort, time delays due to restraint limitations, and ergonomic factors. The assessment helped compare personal fall arrest systems versus fall restraint and anchorage configurations.

Safety Audit and Risk Rating

A structured Hazard Identification and Risk Assessment (HIRA) sheet was used to evaluate potential hazards in each task. Likelihood and severity scores were calculated before and after applying fall protection systems to measure improvement in risk control levels. The results were tabulated and compared to derive experimental conclusions.

VI. DATA COLLECTION AND RECORDING

Data recorded during the experiment included fall arrest distance, anchor deflection, lanyard stretch, net sag depth, and worker usability feedback. Photographs and video footage captured system performance and test accuracy. Survey responses from workers and supervisors were documented for qualitative analysis. Statistical tools were applied to evaluate the effectiveness of system configurations.

EXPERIMENTAL OBSERVATION PARAMETERS

Key parameters examined during the experiment included:

- Arresting forces and shock absorption capability
- Clearance distance required to prevent ground impact
- Anchor strength, stability, and displacement behavior
- System installation time and ease of use
- Worker comfort, fatigue, and work efficiency
- Slippage or instability on fragile or sloped surfaces
- Exposure to swing fall risk in open structural areas
- Damage to roofing sheets due to load concentration

The recorded parameters were compared against recommended standards to evaluate compliance and performance efficiency.

LIMITATIONS OF EXPERIMENTAL SETUP

The experimental testing was subject to certain limitations such as:

- Access restrictions to live roofing areas during heavy wind or rain
- Simulation constraints due to safety restrictions for live worker falls
- Limited availability of advanced fall monitoring technologies for testing
- Time constraints affecting repetitive test cycles

Future research may include real-time digital fall detection systems and automated monitoring platforms to enhance analysis capability.

VII. CONCLUSION

The study concludes that fall protection systems play a critical role in preventing accidents and ensuring worker safety during roofing sheet installation and structural steel erection works. Experimental results confirm that engineered controls such as guardrails, horizontal lifelines, and safety nets significantly reduce fall hazards when properly designed and installed. Personal Fall Arrest Systems (PFAS) were found effective in arresting falls, although user comfort and freedom of movement remain key considerations for practical implementation. Site observations identified that lack of training, poor risk perception, and improper PPE usage are major human factors contributing to fall-related incidents. Safety audits demonstrated measurable improvement in risk reduction when fall protection systems were combined

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with structured safety management practices, inspections, and supervision. Questionnaire responses indicate that worker awareness, competency development, and continuous training are essential for improving safety culture and reducing unsafe acts. Overall, the research emphasizes the need for integrated engineering, administrative, and behavioural strategies to ensure safe working environments and achieve sustainable safety performance in construction roofing and structural jobs.

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