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Risk Characteristics and Prevention Strategies for Scaffolding Dismantling: Case Studies in the Greater Taipei Area

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Abstract*—Scaffolding is the most widely used temporary structure in construction, yet safety management still prioritizes the erection and operational phases, leaving a critical gap in dismantling guidelines. Scaffolding dismantling is a dynamic, high-risk process involving continuous stress redistribution. This study clarifies the dynamic risk characteristics and failure paths during dismantling, then to identify protective blind spots in existing construction plans. In this study, a multi-method approach was adopted: three case sites (a high-rise residential project, a campus renovation, and a large-span hangar) were analyzed, and semi-structured interviews were conducted with six experts from industry, government, and academia. The findings of this study reveal three core failure mechanisms: (1) technical: construction plans remain static and omit dynamic rigidity and residual-stress analysis; (2) managerial: site supervision is insufficient and poorly timed; and (3) behavioral: text-heavy standard operating procedure (SOP) cause cognitive rejection among aging and foreign workers. For these issues, a three-step management procedure is proposed, integrating principles of structural, managerial, and behavioral elements. The procedure features critical-stress warnings, image-based verification, and a three-colored graphic SOP. All these can provide both theoretical insight and practical guidance for improving safety codes and mitigating scaffolding-related disasters.*

***Keywords*—** *Scaffolding dismantling, dynamic risks, failure paths, construction plans, expert interviews.*

I. INTRODUCTION

Scaffolding is one of the most important temporary structures in construction. However, existing safety management systems in Taiwan, from the "Standards for Safety and Health Facilities in the Construction Industry" to related technical manuals, focus predominantly on the erection and use phases [1,2]. Clear regulations cover material specifications, supporting structures, and fall protection, but the dismantling stage lacks concrete and operable technical guidelines. Dismantling is not a simple reverse of erection; it is a dynamic process of stress redistribution in which the progressive removal of wall ties and platforms continuously alters geometric stability and introduces high uncertainty. In the densely built Greater Taipei area with complex micro-climates, these challenges are compounded by high-altitude wind pressure, restricted workspace, and unsafe worker behaviors, rendering the operation highly susceptible to collapses, falls, and falling objects.

This study is motivated by three interrelated practical gaps. First, construction plans commonly treat dismantling as a static reverse procedure and omit systematic assessment of transitional dynamic risks, allowing protective measures to fail unexpectedly. Second, paper-based plans largely serve administrative review rather than first-line guidance; cumbersome text-based standard operating procedures generate cognitive rejection among aging and foreign workers, leading to sequential errors and unsafe acts. Third, economic pressures frequently cause safety measures to be simplified or omitted, and reliance on administrative control alone cannot effectively suppress on-site violations.

The research therefore aims to clarify the dynamic risk characteristics and failure paths of scaffolding dismantling, evaluate the protective blind spots in current construction plans, and develop practical optimization strategies. Three heterogeneous representative sites in Greater Taipei, a high-rise residential project, a campus renovation, and a large-span hangar, were selected for textual dismentalimng of their construction plans. Recent domestic occupational accident cases are incorporated for failure-path back-testing, and semi-structured interviews are conducted with six experts from industry, government, and academia to bridge the gap between written regulations and field practice.

II. LITERATURES REVIEW

This chapter reviews Taiwanese and international technical guidelines, regulatory frameworks, academic literatures, and even occupational accident cases. To clarify the risk characteristics, management gaps, and research development of scaffolding dismantling. These reviews can establish the theoretical foundation for analyzing dynamic risks and developing optimized preventive strategies for scaffolding dismentaling.

Domestic research in Taiwan has long prioritized the erection phase of scaffolding. Only in the past decade have studies begun to examine dismantling-stage risks, failure paths, and early-warning mechanisms. High risk arises mainly from unclear regulations, over-reliance on individual experience, and the dynamic instability of the structure during the transitional removal of members. Representative studies can be grouped into four domains. Accident-cause analyses consistently identify improper dismantling sequences and the premature removal of protective elements (guardrails, braces, and wall ties) as primary triggers of falls and collapses; over-dependence on experiential judgment further obscures latent hazards [12,17,24]. Structural-mechanics research demonstrates that scaffolding is not a static system but undergoes continuous stress redistribution as members are removed; wall ties and base

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restraints are critical for lateral stability, and their untimely release can produce sudden instability [14,15]. Moreover, management aspects studies most highlight regular inspection, inadequate material quality control, and weak verification mechanisms [9,10,13,21,22,25]. Also, some emerging smart-technology applications explore digital systems for configuration planning, material tracking, and work sequence guidance, and to reduce human errors through real-time information supports [7,23].

Meanwhile, several empirical studies further illustrate these points. Cutlip et al. [8] identified the most favorable scaffolding end-frame disassembly techniques and evaluated associated slip potential by measuring whole-body isometric strength and the required coefficient of friction (RCOF). In their study, among seven typical postures, the symmetric front-lift method at knuckle height proved most favorable, with low overexertion risk. Moreover, Mahmud et al. [20], using the Loughborough ConAC model on fatal scaffolding incidents in Malaysia, found that local hazards, supervision, and risk management were the dominant causal factors at successive levels. Abbaszadeh et al. [11] also demonstrated that proper erection and dismantling practices are among the factors most strongly correlated with overall scaffolding safety; the highest human-error risk was associated with failure to reattach braces and connections before dismantling.

In additon, Yalçın [19] analyzed 280 reports from 2019-2023, identified that loss of balance, brace failure or collapse, and falling objects as the leading causes of falls from scaffolding. Kim et al. [16] integrated temporary structures into a BIM-based safety-checking platform that automatically detects hazards related to scaffolding activities and visualizes preventive measures before construction begins. Ohdo et al. [18] developed and experimentally validated a safer assembling and dismantling method for system scaffolding that incorporates the use of safety harnesses.

A comparative review of regulations reveals a pronounced "heavy-on-erection, light-on-dismantling" bias in Taiwan's Standards for Safety and Health Facilities in the Construction Industry. Detailed quantitative requirements exist for erection (material strength and wall-tie spacing), yet dismantling lacks concrete indicators for residual-stress assessment, free-end reinforcement, or real-time work permits. In contrast, U.S. standards mandate continuous monitoring by competent persons, while U.K. guidance requires design-stage structural calculation of dismantling sequences and promotes visual work-permit systems [3,4]. These differences highlight three practical blind spots in current Taiwanese practice: plans remain administrative documents rather than operable tools; inspection remains static rather than synchronized with rising risk nodes; and text-heavy procedures generate cognitive rejection among aging and foreign workers.

Synthesizing the literature, three consistent insights emerge. First, dismantling risks are highly dynamic and require the simultaneous management of structural behavior and worker actions. Second, standardized sequences combined with visual checklists effectively reduce variability in human judgment. And third, digital and visualization tools can bridge the communication gap between regulations and in-site practice. .

III. METHODOLOGY

This study adopts a multi-method qualitative framework that integrates the textual dismentaling of construction plans, failure-path analysis of occupational accidents, and practical validation through expert interviews. This research design aims to identify gaps among regulatory requirements, written plans, and on-site execution, while developing an operable optimization tool for scaffolding dismantling safety.

Three representative sites with distinct construction characteristics in the Greater Taipei area were selected for systematic content analysis of their construction plans (Table 1): a high-rise residential project, a campus renovation project, and a large-span hangar project. The analysis focused not only on formal regulatory compliance but also on whether the plans adequately anticipated dynamic stress redistribution, free-end instability, and procedural violations during the transitional dismantling stage. In addition, recent major domestic and international scaffolding accident cases were used as negative test cases. The failure paths identified from these cases were compared with the content of the construction plans to assess the actual protective effectiveness of existing technical, administrative, and behavioral controls.

To bridge the gap between static documentation and field practice, semi-structured interviews were conducted with six experts from industry, government, and academia (Table 2). The participants included a labor-inspection officer, an engineering consultant, a project manager, a site superintendent, a safety and health officer, and a scaffolding contractor. Collectively, they provided expertise in regulatory enforcement, structural assessment, cost – schedule trade-offs, front-line supervision, worker behavior, and practical scaffolding operations.

TABLE 1. Textual dismantling plans for three case sites.

	Case 1	**Case 2**	**Case 3**
Site Conditions	>20 floors urban high-rise building	Elementary school campus renovation	Large-span hangar
Risk Inference	Core risk on high-wind-pressure zone and critical stability nodes of the final three floors	Principal risk is structural instability of free-end from segmented dismantling	Strength lies in integrating technical specifications with administrative enforcement

TABLE 2. Profiles of interview participants.

	Title / Background	**Years of Experience**
Expert-1	Occupational safety and health inspector	12
Expert-2	Engineering consultant	20
Expert-3	Project manager	16
Expert-4	Site supervisor	18
Expert-5	Safety and health administrator	7
Expert-6	Scaffolding contractor	10

The interview questions were organized around five complementary dimensions: (1) risk identification during

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dismantling; (2) difficulties in on-site management; (3) preventive measures and improvement strategies; (4) the applicability of inspection and verification tools; and (5) institutional and training-related issues. The analysis also took into account each expert's professional role and area of authority when interpreting the responses. Finally, triangulation was conducted across the construction plans, accident cases, and expert testimony to reduce the bias associated with any single perspective. This process helped ensure that the proposed three-step Management procedure is both theoretically and practically feasible.

IV. Study Results

The documental analysis of the three construction plans, supplemented by semi-structured expert interviews, revealed that although all three cases satisfied formal administrative review requirements, they remained systematically inadequate in identifying dynamic risks, preserving dismantling sequences, and guiding on-site behavior during scaffolding dismantling (Table 3). In general, the plans treated dismantling as a static reversal of erection and therefore failed to address the progressive loss of structural rigidity and the continuous redistribution of internal forces.

TABLE 3. Protective strategies in the dismantling plans of three case sites.

	Case 1	Case 2	Case 3
Structural Stability Planning	Weak	Moderate	Excellent
Wall-Tie Dismantling Control	Moderate	Moderate	Good
Fall Protection Planning	Moderate	Excellent	Good
Procedural Error Prevention	None	Moderate	Excellent

In the high-rise residential case, main risk was concentrated in the upper wind-exposure zone and the final three scaffolding levels. However, the plan provided only general statements concerning dismantling sequence. In the campus renovation case, staged dismantling created discontinuous free ends at vertical interfaces. Although the plan included strong environmental isolation measures, it did not provide sufficient details regarding temporary shear bracing or geometric reinforcement. Finally, for the large-span hangar case, its formal work-permit system and symmetrical dismantling protocol transformed general structural principles into enforceable administrative checkpoints. Nevertheless, cross-comparison with historical accident cases showed that premature wall-tie removal, free-end instability, and procedural shortcuts remained the dominant failure paths that existing plans were unable to adequately intercept. These failure patterns correspond to the risk zones and key nodes illustrated in the schematic diagram of dismantling zoning (Figure 1).

Because the internal forces within a scaffolding change continuously and may become difficult to predict during dismantling, conventional static checks at individual nodes are insufficient to capture changes in structural safety. An active and continuous monitoring mechanism is therefore required. This mechanism should use a critical-stress value as an early-warning threshold. When monitoring data approach the predefined safety margin, an emergency response procedure should be activated. Such a system can reduce the escalation of risk caused by delayed information, delayed decision-making, or delayed intervention (Figure 2).

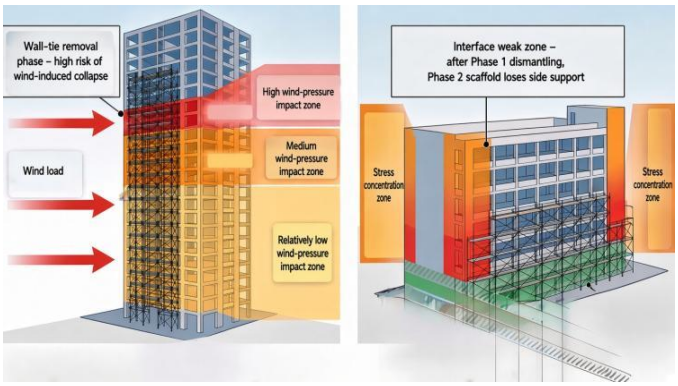


Fig. 1. Schematic diagram of dismantling zoning and key risks (AI generated).

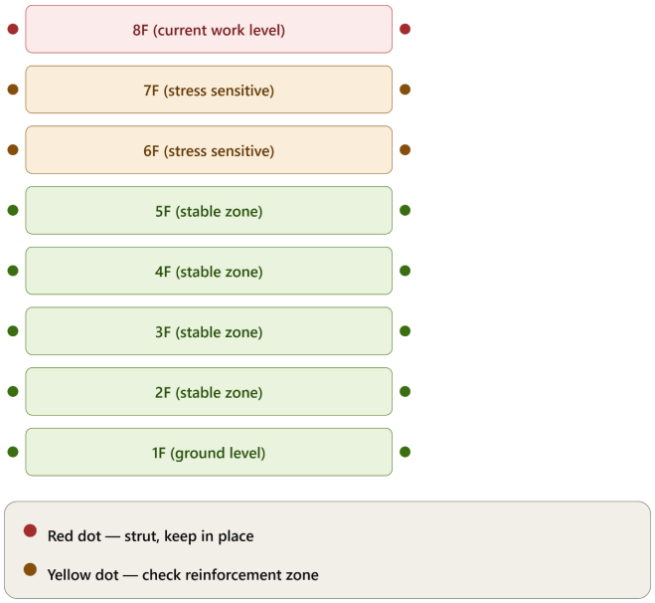


Fig. 2. Critical-stress warning.

The expert interviews expanded the findings from the document analysis across five dimensions. First, risk identification was lack by the limited visibility of changes in structural stability. Workers sometimes removed entire rows of wall ties just for convenience, while construction plans often failed to designate these components as critical structural members. Second, time schedule pressure frequently took precedence over the prescribed dismantling sequence, particularly when safety-related costs were not separately identified in the project budget. Third, physical fatigue and restricted working space encouraged workers to throw materials rather than transport them through approved methods. Experts therefore recommended that vertical transportation equipment be contractually required and made more convenient than manual handling. Fourth, conventional checklists were considered too cumbersome for the rapid pace of dismantling operations. Image-based verification of critical nodes and color-coded icon-graphic SOP were viewed as more effective in improving compliance, particularly among older workers and

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workers with limited proficiency in the site's primary language. Finally, these experts recommended that risk-based regulatory requirements are needed, including mandatory residual-stress sign-off and quantified wind-speed thresholds for buildings above a specified height. They also advocated pocket-card training to convert tacit knowledge into explicit and visually accessible safety rules.

Taken together, the findings indicate three interrelated failure mechanisms. At the technical level, construction plans lack adequate procedures for dynamic rigidity assessment and residual-stress analysis. At the managerial level, supervision is insufficiently and is not adequately synchronized with high-risk dismantling nodes. At the behavioral level, text-heavy procedures increase cognitive burden and discourage consistent compliance. These findings provide the empirical foundation for the proposed three-step management procedure, which integrates three components: critical-stress warning, image-based verrification, and a three-colored icon-graphic SOP.

To address inspection difficulties and management blind-spots during high-altitude operations, a dual-control mechanism combining image verification with mandatory stop points was introduced (Figure 3). At designated critical nodes, workers must immediately submit photographic evidence for review and record-keeping. And the next dismantling stage will not begin until the submitted images have been verified and approvaled. This "no confirmation, no progression" rule can shift site management from reactive, post-event inspection to proactive prevention of procedural violations.

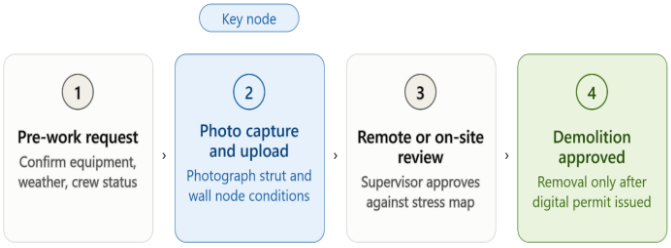


Fig. 3. Flow of the image-based work-permit system.

To reduce the cognitive burden experienced by front-line workers in complex and rapidly changing environments, a visualized SOP was developed together with a red-yellow-green visual management system (Figure 4). Intuitive symbols help overcome language and experience barriers, thereby improving consistency in workers' understanding and execution of safety procedures. The visual system also provides immediate prompts when workers experience physical fatigue or attempt to perform unplanned tasks. In this way, it functions as an on-site behavioral intervention rather than merely as a supplementary instruction sheet.

The interaction among the major failure mechanisms can be described as follows. As the removal of structural components progressively weakens scaffolding rigidity, external wind pressure may introduce additional disturbances. If supervision and verification are absent, an administrative control gap emerges at the same time. These technical, environmental, and managerial conditions can interact at stress-concentration nodes and trigger a chain reaction throughout the scaffolding. The resulting collapse process is therefore not caused by a single isolated error. The evolution of the failure path during scaffolding dismantling is illustrated in Figure 5.



Fig. 4. Graphical three-colored management SOP.

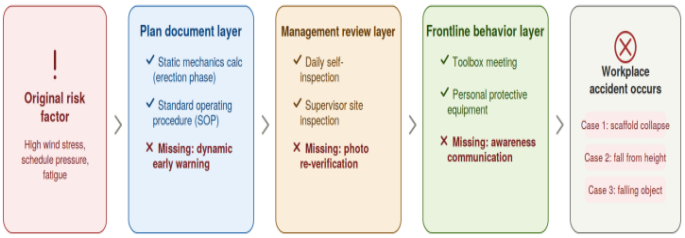


Fig. 5. Failure paths analysis of scaffolding dismantling.

V. Conclusion and Recommendations

This study examined safety management during the dismantling of scaffolding by analyzing three representative cases in greater Taipei area, and interviewing six experts from industry, government, and academia. Cross-validation of these sources demonstrates that dismantling accidents arise from the dynamic interaction of structural, managerial, and behavior factors, and current plans and practices remain inadequate for managing this transitional process.

Scaffolding dismantling is not simply the reverse of erection. It is a highly dynamic process involving continuous stress re-distribution and progressive loss of rigidity. Any improper sequence in the removal of wall ties, braces, or other stabilizing members can trigger chain-reaction failures, and thereby increasing the risks of collapse and falls. Although existing construction plans are administratively compliant, they largely treat dismantling as a static procedure. Stand-alone checklists and inspection regimes remain document-oriented and fail to capture real-time structural changes. The dominant risk sources are therefore structural, managerial, and behavioral. Structural risks include the untimely removal of wall ties, free-end instability, and local force imbalances. Managerial risks include insufficient dynamic supervision, incomplete verification, and delayed feedbacks. Finally, behavioral risks include experience-based shortcuts, inadequate risk perception, language barriers, and time schedule driven unsafe acts.

In response these issues, this study proposes a three-step management procedure that integrates three complementary layers, i.e., a critical-stress warning mechanism for continuous monitoring, an image-based verification workflow that transforms key hold points into enforceable and traceable checkpoints, and finally a three-colored graphic SOP that replaces text-heavy instructions. Together, these measures

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enhance risk identification, managerial accountability, and front-line compliance.

The practical recommendations from this study are as follows: (1) to incorporate staged dismantling sequences and mandatory hold points into construction plans; (2) to adopt image-based verification to create auditable, real-time records; and (3) to convert safety rules into color-coded visual guides. Furthermore, the future research may also explore digital-twin and sensor-based real-time monitoring, extend empirical validation to coastal and strong wind environments, and investigate how cultural and linguistic diversity within the construction workforce that shapes risk perception and behavior. All these works could transform scaffolding dismantling from a residual high-risk activity into a systematically controlled process.

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