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Near-Miss-Informed Occupational Safety Risk Assessment of Upper-Structure Construction Using HIRARC Method

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Abstract. Near-miss observations can reveal hazards that require attention before construction accidents occur. This study assessed upper-structure work at a building construction project in Indonesia using the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method. Observations, interviews, job safety analysis, expert review, and questionnaires completed by 31 project personnel were used to identify and assess hazards. Twenty-one indicators were retained for analysis. The reported Cronbach's alpha values were 0.955 for likelihood and 0.967 for severity. Eight indicators obtained a risk score of 6, while thirteen indicators obtained a score of 4, all were classified as low-to-medium risk according to the project risk matrix. The higher-scoring indicators involved sharp materials, scaffolding, material handling, reinforcement fabrication, and access conditions. Engineering controls, task-specific supervision, housekeeping, and appropriate personal protective equipment were proposed. The assessment supports local risk-control prioritization, although perception-based severity ratings and the absence of before-and-after measurements limit conclusions regarding accident reduction.

Keywords: construction project, HIRARC, near miss, occupational safety, risk assessment

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1. Introduction

Construction projects involve dynamic site conditions, simultaneous activities, heavy material handling, work at height, and the use of various tools and equipment. In upper-structure construction, scaffolding, material movement, reinforcement fabrication, and formwork installation expose workers to falls, falling objects, slips, and injuries caused by contact with materials or equipment [1]. Occupational health and safety management is therefore necessary to identify hazards, establish intervention priorities, and ensure that controls are appropriate to the working conditions [2].

Near-miss incidents are events that do not result in injury but could lead to accidents under different circumstances [3],[4]. Such events can provide early indications of unsafe conditions, unsafe acts, or

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weaknesses in existing controls. Woźniak and Hoła[5] demonstrated that examining the characteristics and causes of near misses can inform accident-prevention measures in construction. Li, Lin, and Jin [6] also emphasized the benefits of near-miss monitoring and early warning. Therefore, near-miss information should prompt hazard identification and control evaluation, even when no injury has occurred[7].

Hazard Identification, Risk Assessment, and Risk Control (HIRARC) is an approach used to manage occupational safety risks. It connects task-specific hazard identification with the assessment of likelihood and severity and the selection of appropriate control measures. Wibowo, Pangastuti, and Parningotan [8] applied HIRARC to assess occupational safety risks at the HDI Hive Menteng building. Nababan, Walangitan, and Pratasis [9] combined Job Safety Analysis (JSA) with HIRARC at the Christian Center construction project in Manado, while Pramesthi, Anwar, and Susanti [10] identified equipment and material-related hazards in building construction. These studies demonstrate how activity-based assessments can establish risk profiles that reflect project characteristics

HIRARC also provides a basis for developing control measures. Arumsari [11] examined occupational safety risks in building construction, whereas Daud, Budihardjo, and Isnanto[12] evaluated risks during the construction of a bulk-water supply system. Kabul and Yafi [1] identified 11 risks associated with tower-crane material-lifting activities, including two extreme and four high-risk conditions. Studies conducted in a construction company in Cilegon [2] and among construction safety supervisors [13] further highlight the importance of considering work activities and personnel roles. However, risk classifications cannot be compared directly across studies without accounting for differences in assessment scales, hazard exposure, work scope, and existing controls.

These studies provide a methodological foundation for HIRARC application. However, the use of near-miss information requires a clear link between observed conditions, hazard indicators, and proposed control measures. This need is particularly relevant to upper-structure construction, where sharp materials, unstable footing, falling objects, and restricted access may occur simultaneously. Near-miss observations can enrich hazard identification, while likelihood and severity assessments help establish intervention priorities. Such assessments must also distinguish the absence of injury in a near miss from the potential consequences of an actual accident.

At the Pertamina Research and Technology Center construction project in Jakarta, observations of falling materials or debris that nearly struck personnel and unstable footing that nearly caused workers to fall provided inputs for assessing upper-structure hazards. This study integrates field observations, interviews, JSA, expert validation, and questionnaires completed by 31 project personnel within the HIRARC process. Its contribution is a project-specific hazard register and control priorities that connect near-miss observations with personnel assessments and task information. The study also considers the limitations of perception-based assessments when hazards with different potential consequences receive the same severity category.

Accordingly, this study aims to identify potential hazards in structural preparation, reinforcement, and formwork activities using near-miss observations and supporting field data; assess their likelihood, severity, and overall risk levels using HIRARC; and formulate control measures based on the hierarchy of controls and the project risk matrix. The findings are intended to support local control prioritization and provide a basis for subsequent occupational safety evaluations.

2. Methods

This study employed a descriptive case-study approach, combining quantitative questionnaire assessments with qualitative information from field observations, interviews, and document review. The research was conducted at the Pertamina Research and Technology Center construction project in Jakarta and focused on three upper-structure work groups: structural preparation, reinforcement fabrication, and formwork installation. Hazard Identification, Risk Assessment, and Risk Control (HIRARC) was applied to identify hazards, evaluate occupational safety risks, and formulate control recommendations.

2.1. Research stages

The research comprised hazard identification, expert review, questionnaire assessment, instrument testing, risk scoring, and control development. Figure 1 presents research stages.



Figure 1. Research stages

Upper-structure activities were first reviewed to establish the assessment scope. Field observations, including observations of near-miss conditions, interviews, and project Job Safety Analysis (JSA) documents were then used to develop an initial hazard list. Near-miss observations informed hazard identification but were not used to calculate incident frequency. Experts reviewed the indicators for their relevance to project conditions. Subsequently, project personnel assessed the likelihood and severity of the identified hazards through questionnaires. The responses were evaluated using item–total correlation and internal consistency tests before the retained indicators were included in the final risk assessment. Control recommendations were developed by considering the identified hazards, assessed risk scores, and hierarchy of controls.

2.2. Data collection

Primary data were collected through field observations, interviews with project personnel, expert review, and questionnaires. Observations and interviews provided information on upper-structure work activities, hazardous conditions, and existing safety practices. Observed near-miss events included falling materials or debris that nearly struck personnel and unstable footing that nearly caused workers to fall. These observations contributed to the identification of falling-object and fall-related hazards in structural preparation, reinforcement, and formwork activities.

Project Job Safety Analysis (JSA) documents provided supporting information for identifying and interpreting task-specific hazards. Near-miss observations were considered alongside field information and documentary evidence as inputs to hazard identification. They were not used to estimate incident frequency because an event-level register documenting occurrence dates, exposure hours, and links to individual questionnaire indicators was unavailable for this analysis.

2.3. Respondents and expert review

The risk assessment involved 31 project personnel selected through purposive sampling based on their involvement in project activities and knowledge of working conditions. Respondents comprised supervisors, safety officers, HSE officers, and QHSE personnel. Because the research documentation contains inconsistent minimum work-experience criteria, respondent characteristics were reported using the actual profile without assuming that all participants met a uniform experience threshold.

Three QHSE experts, each with five years of work experience, reviewed the initial hazard indicators to assess their relevance to project conditions. At the final stage, one expert reviewed the assessment findings and proposed risk-control measures.

The questionnaire included separate assessments of likelihood and severity. Likelihood ratings reflected respondents' perceptions of the possibility that a hazardous event could occur, while severity ratings reflected the potential consequences if the event resulted in an accident. Both dimensions were assessed using five-point scales.

2.4. Hazard indicators

The initial hazard list comprised 24 indicators developed from near-miss observations, field observations, interviews, project Job Safety Analysis (JSA) documents, and supporting literature. The near-miss observations included falling materials or debris that nearly struck personnel and unstable footing that nearly caused workers to fall. These observations helped direct hazard identification toward falling-object and fall-related hazards. However, near-miss observations were not used to calculate incident frequency. Table 1 present hazard indicators retained for the final HIRARC assessment.

Table 1. Hazard indicators retained for the final HIRARC assessment

Work group	Code	Hazard condition or potential event
Structural preparation	X1.1	Injury from sharp materials during project-fence preparation
Structural preparation	X1.2	Fall during preparation for beam and slab concreting
Structural preparation	X1.4	Fall during steel-scaffold assembly
Structural preparation	X1.5	Slip or fall during material preparation due to disorganized materials
Structural preparation	X1.6	Struck by falling materials during scaffold assembly
Reinforcement	X2.1	Cut or scratch from tie wire during reinforcement fabrication
Reinforcement	X2.3	Hand puncture from reinforcing steel during fabrication
Reinforcement	X2.4	Electric shock during reinforcement fabrication or welding
Reinforcement	X2.5	Hand puncture from tie wire during tying or cutting
Reinforcement	X2.6	Struck by reinforcing steel during tower-crane lifting
Reinforcement	X2.7	Slip or fall in inadequately marked fabrication areas
Formwork	X3.1	Poorly arranged materials obstructing formwork fabrication
Formwork	X3.2	Nail puncture during formwork fabrication

Formwork	X3.3	Struck by formwork during lifting
Formwork	X3.4	Body part trapped during beam and slab formwork installation
Formwork	X3.5	Wood-splinter puncture during formwork fabrication
Formwork	X3.6	Safety noncompliance associated with potential falling-object exposure
Formwork	X3.7	Hand cutting injury during wood cutting for formwork
Formwork	X3.8	Hammer impact injury during formwork fabrication
Formwork	X3.9	Slip or fall due to formwork oil
Formwork	X3.10	Drill-related injury during formwork fabrication

Following expert review and instrument testing, 21 indicators were retained for the final analysis: five for structural preparation, six for reinforcement work, and ten for formwork work. The indicators covered hazards related to sharp materials, scaffold assembly, falling materials, reinforcement fabrication, electrical exposure, obstructed access, slippery surfaces, and tool-related injuries. The original indicator codes were retained in the final analytical set to maintain traceability to the source tables. The excluded indicators were X1.3, X2.2, and X2.8. Because the source documents do not fully explain the reduction from 24 to 21 indicators, no additional exclusion criteria were inferred.

2.5. Validity and reliability testing

The questionnaire instrument was tested for validity and reliability before being used for risk assessment. Validity testing was conducted to determine whether each questionnaire item measured the intended hazard indicator. Reliability testing was conducted to evaluate the internal consistency of responses for the likelihood and severity variables.

The reported Cronbach's alpha values were 0.955 for likelihood and 0.967 for severity. These values indicate a high level of internal consistency for both assessment variables. Therefore, the questionnaire results were considered appropriate for use in the subsequent HIRARC analysis.

2.6. Risk assessment

Risk assessment was conducted by combining the likelihood and severity ratings for each hazard indicator. The likelihood score represented the probability that a hazardous condition or near-miss event could occur, while the severity score represented the potential consequence if an accident occurred.
The risk score was calculated using the following equation:

$$Risk\ Score = Likelihood\ Score\ x\ Severity\ Score \quad (1)$$

Each score was classified using the project risk matrix, as presented in Table 2. The resulting classifications supported local control prioritization. Since the ratings were based on respondents' perceptions, they were not interpreted as measured incident probabilities or objectively verified accident consequences.

Table 2. Risk classification based on the project matrix

Risk score	Risk category
1	Insignificant
2–3	Low
4–6	Low-to-medium
8–12	Medium-to-high
15–25	High

2.7. Risk control

Risk-control measures were formulated based on the risk levels and the hierarchy of controls. The proposed controls prioritized engineering measures, such as improving work platforms, guarding sharp

materials, securing scaffolding, and controlling material movement. Administrative measures included task-specific supervision, safe work procedures, housekeeping improvement, toolbox meetings, and routine inspections.

Personal protective equipment was proposed as a supporting control measure, particularly for hazards that could not be eliminated through engineering or administrative controls. The proposed controls were intended to reduce the likelihood or severity of the identified hazards and to support local control prioritization in the project.

3. Results and Discussion

This section presents the results of the HIRARC-based occupational safety risk assessment for upper-structure construction activities. The results include respondent characteristics, questionnaire validity and reliability, hazard indicators, likelihood and severity assessments, risk scores, and recommended control measures. The discussion focuses on the prioritization of hazards and the formulation of preventive controls based on near-miss observations, field information, expert review, and personnel assessments.

3.1. Respondent characteristics and instrument assessment

The assessment involved 31 project personnel comprising 11 supervisors (35.5%), nine safety officers (29.0%), five HSE officers (16.1%), and six QHSE personnel (19.4%). Four respondents (12.9%) had less than six months of work experience, six (19.4%) had six to twelve months, twelve (38.7%) had one to three years, and nine (29.0%) had three to five years. The involvement of respondents with different roles provided a broader perspective on the hazards in upper-structure work. Field workers could provide information based on direct exposure to work activities, while supervisors and safety personnel could contribute information related to work procedures, supervision, and existing safety-management practices.

All 21 retained indicators exceeded the item–total correlation reference value of 0.355 used in the source study. Correlation coefficients ranged from 0.385 to 0.859 for likelihood and from 0.378 to 0.884 for severity. Cronbach's alpha values were 0.955 and 0.967 for likelihood and severity, respectively, indicating high internal consistency within both questionnaire dimensions.

3.2. Hazard distribution and risk scores

Table 3 presents the distribution calculated from the final source risk tables. The 21 indicators comprised 5 preparation indicators, 6 reinforcement indicators, and 10 formwork indicators. Eight indicators (38.1%) had scores of 6 and thirteen (61.9%) had scores of 4. All indicators therefore fell within the low-to-medium category defined by the project matrix. The score-6 group represents a higher priority within that category; it is not a high-risk category.

Table 3. Distribution of assessed indicators by work group

Work group	Indicators	Score 6	Score 4
Preparation	5	4	1
Reinforcement	6	3	3
Formwork	10	1	9
Total	21	8	13

The reported likelihood means ranged from 2.00 to 2.74. The highest mean was associated with falling during scaffold assembly (X1.4). All integer severity categories were 2, so the score difference resulted entirely from likelihood categories: L = 3 produced R = 6 and L = 2 produced R = 4. Table 4 retains the original indicator codes while shortening the hazard descriptions for readability. It gives the complete analytical set, preventing the higher-scoring indicators from obscuring other potentially consequential hazards.

Table 4. Complete risk profile for the 21 retained indicators

Code	Hazard or risk description	L	S	R
X1.1	Injury from sharp material during fence preparation	3	2	6
X1.2	Fall during beam and slab concreting preparation	2	2	4
X1.4	Fall during steel scaffold assembly	3	2	6
X1.5	Slip or fall during disorganized material preparation	3	2	6
X1.6	Struck by material during scaffold assembly	3	2	6
X2.1	Cut or scratch from tie wire during reinforcement fabrication	3	2	6
X2.3	Hand puncture from reinforcing steel during fabrication	3	2	6
X2.4	Electric shock during reinforcement fabrication or welding	2	2	4
X2.5	Hand puncture from tie-wire tying or cutting	2	2	4
X2.6	Struck by reinforcing steel during tower-crane lifting	2	2	4
X2.7	Slip or fall in inadequately marked fabrication areas	3	2	6
X3.1	Poorly arranged materials obstruct formwork fabrication	2	2	4
X3.2	Nail puncture during formwork fabrication	2	2	4
X3.3	Struck by formwork during lifting	2	2	4
X3.4	Body part trapped during formwork installation	2	2	4
X3.5	Wood splinter puncture during formwork fabrication	3	2	6
X3.6	Safety noncompliance with potential falling-object exposure	2	2	4
X3.7	Hand cutting injury during wood cutting	2	2	4
X3.8	Hammer impact injury during formwork fabrication	2	2	4
X3.9	Slip or fall due to formwork oil	2	2	4
X3.10	Drill-related injury during formwork fabrication	2	2	4

The higher-scoring indicators show recurring material-contact and movement-related mechanisms. Sharp-material exposure occurs during fence preparation, reinforcement fabrication, and formwork fabrication. Falls and struck-by events are associated with scaffold assembly, material preparation, and access within fabrication areas. These mechanisms suggest that organized storage, protection of exposed sharp elements, stable working platforms, and separation from moving materials are relevant control priorities.

3.3. Near-miss information and interpretation of risk scores

Observed near misses involved falling materials or debris that nearly struck personnel and unstable footing that nearly caused workers to fall. These observations correspond to falling-object and access-related mechanisms in the hazard register and provided inputs for identifying potential accident scenarios.

However, an event-level register linking individual near misses to questionnaire indicators, occurrence dates, and exposure duration was unavailable. The findings therefore represent a near-miss-informed risk assessment rather than a quantitative analysis of near-miss frequency. The percentage of score-6 indicators cannot be interpreted as the percentage of near-miss events or the probability of an accident.

Woźniak and Hoła [5] demonstrated the value of registered construction events for examining event types and causes, while Li, Lin, and Jin [6] emphasized near-miss monitoring and early warning. Their approaches indicate how structured reporting could strengthen the connection between observed events, assessed hazards, and corrective actions at the present project.

The uniform severity category also requires careful interpretation. Minor contact injuries, electric shock, falls, and suspended-load incidents can have substantially different potential consequences. Averaging ordinal responses may obscure severe judgments expressed by some respondents. Moreover, the absence of injury during a near miss does not establish that an actual accident would have minor

consequences. Specialist review of credible severity scenarios remains necessary, particularly for work at height, electrical activities, and lifting operations.

3.4. Interpretation and comparison with previous studies

The results show that all 21 retained indicators were classified as low-to-medium risk according to the project risk matrix. Eight indicators obtained a risk score of 6, while 13 indicators obtained a score of 4. Therefore, the score-6 indicators should be prioritized within the low-to-medium category, although none of the indicators was classified as high risk.

The higher-scoring indicators were mainly associated with sharp materials, scaffold assembly, material handling, reinforcement fabrication, and access conditions. These findings are consistent with previous HIRARC studies, which identified falls, falling objects, material-handling risks, and injuries caused by tools or sharp materials as common construction hazards. Similar to earlier studies, the results indicate that task-specific assessment is important because the dominant hazards differ across work activities and site conditions [1].

Previous construction studies by Wibowo et al. [8] demonstrate the application of HIRARC to task-specific hazards. The present study follows a similar assessment structure while incorporating near-miss observations into hazard identification. Nevertheless, differences in activities, exposure conditions, rating scales, and risk matrices limit direct comparisons between studies. A low-to-medium classification in this project should therefore be interpreted within its assessment framework rather than treated as equivalent to the same label in another project.

An organizational perspective is provided by Mirnayani [14] , who used FAHP and fishbone analysis to examine occupational safety and health management implementation in a river-estuary construction project. That study identified communication difficulties and limited understanding of safety requirements among the issues associated with behavioural safety. These findings support consideration of clear work instructions, task-specific supervision, and accessible reporting channels when implementing the proposed controls. Their effectiveness in the present project, however, requires subsequent evaluation.

The ergonomic assessment by Mirnayani, Noor Aulady, and Novianto [15] offers a complementary perspective by examining awkward postures, repetitive activities, and manual material handling using RULA, REBA, and the Nordic Body Map. Although reinforcement and material-handling activities were included in the present study, dedicated ergonomic measurements were not conducted. The reported risk categories consequently do not establish the level of ergonomic exposure. Combining HIRARC with posture assessments and worker discomfort surveys could provide a more comprehensive evaluation of these activities.

Compared with previous studies that assessed risks primarily through work-activity analysis, field inspections, or expert judgment, this study used near-miss observations as an additional input for hazard identification. The near-miss observations helped direct attention to falling-object and fall-related hazards, particularly those associated with unstable working platforms and materials that nearly struck personnel. This approach is consistent with previous research showing that near-miss reporting can provide early indications of unsafe conditions and support preventive safety management.

However, the comparison with previous studies should be interpreted carefully. Risk classifications cannot be directly compared across projects because assessment scales, hazard exposure, work scope, existing controls, and respondent perceptions may differ. In this study, all severity categories were rated as 2, so the differences in risk scores were determined solely by the likelihood categories. This condition also shows that a higher risk score does not necessarily indicate a more severe potential consequence; it may reflect a higher perceived likelihood of occurrence.

The absence of an event-level near-miss register also limits the interpretation of the results. Because individual near-miss events could not be linked to specific questionnaire indicators, occurrence dates, or exposure duration, the study could not calculate near-miss frequency or establish a statistical relationship between near-miss events and risk scores. Therefore, the findings should be interpreted as a near-miss-informed risk assessment rather than a quantitative analysis of near-miss frequency.

Overall, the results support the use of HIRARC as a structured method for identifying hazards, assessing risks, and prioritizing controls in upper-structure construction activities. The integration of near-miss information provides an additional preventive perspective, although its effectiveness would be stronger if supported by complete event records, consistent severity assessment, and follow-up measurements before and after control implementation.

3.5. Proposed controls and implementation priorities

Control recommendations were developed by considering the identified hazard mechanisms, assessed risk scores, and hierarchy of controls. Although all indicators were classified as low-to-medium risk, the eight indicators scoring 6 were assigned higher implementation priority within the assessment. These indicators concerned sharp fencing materials, scaffolding-related falls, disordered materials, falling scaffolding components, tie-wire injuries, exposed reinforcement, unmarked fabrication areas, and wood splinters. The proposed measures are presented in Table 5.

Table 5. Proposed controls and implementation priorities

Hazard group	Proposed controls	Implementation priority
Sharp fencing materials, tie wire, exposed reinforcement, and wood splinters	Remove protruding sharp ends where practicable; protect exposed reinforcement; deburr or replace damaged materials; provide suitable handling tools and task-appropriate gloves.	Prioritize indicators scoring 6; inspect materials before handling.
Falls associated with scaffolding and unstable footing	Provide secure working platforms, guardrails, and safe access; inspect scaffolding before use and after modifications; restrict access to incomplete or defective platforms.	Correct observed defects before work proceeds, regardless of the questionnaire score.
Falling scaffolding components and other materials	Secure components and stored materials; provide appropriate edge protection; establish exclusion zones beneath overhead activities; coordinate lifting and simultaneous work.	Address unsecured materials and overhead exposure before the activity begins.
Disordered materials and unmarked fabrication areas	Establish designated storage and fabrication zones; separate pedestrian routes from work areas; remove waste and obstructions; maintain visible access markings.	Prioritize locations associated with indicators scoring 6 and maintain housekeeping throughout the shift.
Formwork installation, cutting, drilling, and hammering	Secure workpieces; maintain equipment guards; use suitable tools; provide safe hand positions and task-specific instructions; inspect equipment before use.	Apply controls before each task and verify them during routine supervision.
Protruding nails and slippery surfaces	Remove or secure protruding nails; promptly clean oil spills; provide suitable storage for dismantled formwork and maintain clear walkways.	Correct hazardous conditions when identified.

Implementation should begin with eliminating hazards where practicable, followed by substitution and engineering controls. For the assessed activities, this includes removing unnecessary sharp projections, selecting safer tools or materials where feasible, securing platforms, and physically separating workers from falling-object exposure. Administrative measures, including inspections,

supervision, work coordination, and toolbox meetings, should support these physical controls. Personal protective equipment should provide additional protection against remaining exposure.

Implementation priority should also reflect current site conditions and credible accident consequences. A lower questionnaire score should not delay correction of an unstable platform, an unprotected edge, or unsecured overhead materials. Such conditions require assessment and correction before the affected work continues. This is particularly relevant because the uniform severity category limited differentiation between hazards in the present analysis.

Responsibilities should be assigned to the personnel responsible for each work activity, with safety personnel supporting verification and follow-up. Supervisors should confirm that controls are in place before work begins, while workers should have a clear channel for reporting near misses and unresolved hazards. A corrective-action record should document the hazard, responsible person, completion date, and verification outcome.

The proposed measures were not evaluated through a post-implementation assessment. Their effectiveness therefore remains to be established. Follow-up inspections, records of recurring hazardous conditions, and near-miss reports with activity and exposure information would support subsequent evaluation. Reporting trends should be interpreted carefully, because an increase in reported near misses may reflect improved reporting participation as well as changes in exposure.

4. Conclusion

The HIRARC assessment organized 21 upper-structure indicators across preparation, reinforcement, and formwork at the Research and Technology Center Pertamina project. The numerical source results place eight indicators at score 6 and thirteen at score 4, all within the project-specific low-to-medium category. The eight higher-scoring indicators point to material contact, scaffold assembly, falling materials, and work-area access as local priorities. Controls should address these mechanisms while specialist review checks the credible severity of falls, electrical exposure, and lifting operations. Near-miss observations provide useful inputs for this process, but the available evidence supports prioritization of proposed controls rather than a demonstrated reduction in accidents. Documented event reporting and post-control reassessment are needed to evaluate subsequent improvement.

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