



Integrating Rebound Hammer Testing into Structural Reanalysis for Capacity Assessment of Existing Reinforced Concrete Buildings

I Nyoman Ardika¹, I G.A. Arie Krismayanti¹,
and Putu Ryan Priyatna¹

¹Civil Engineering Department, Politeknik Negeri Bali, Bali, Indonesia
nyomanardika@pnb.ac

Abstract. Existing reinforced concrete buildings often require structural assessment due to aging, changes in building function, uncertainties in construction quality, or the unavailability of reliable construction records. This study proposes an Integrated Structural Assessment Framework (ISAF) that transforms field investigation results into Actual Structural Parameters for structural reanalysis and engineering decision-making. The proposed framework was applied to a three-story reinforced concrete residential building in Tabanan, Bali, Indonesia. Rebound Hammer testing was conducted at 80 test locations distributed across columns, beams, and slabs, with 30 impacts performed at each test location. The estimated concrete compressive strengths were statistically processed, converted into equivalent cylinder compressive strengths, and incorporated as Actual Structural Parameters in the structural reanalysis based on SNI 2847:2019. The minimum equivalent cylinder compressive strength obtained was 19 MPa. The structural reanalysis results indicated that all primary structural elements satisfied the required strength capacity, with no elements identified as overstressed. Furthermore, the required reinforcement ratios remained within the limits specified by the applicable standard, indicating adequate structural strength, stability, and efficiency. The proposed ISAF demonstrates that Rebound Hammer testing can serve not merely as a technique for estimating concrete compressive strength, but also as a source of reliable and verified structural information to support evidence-based and systematic engineering decision-making in the assessment of existing reinforced concrete buildings.

Keywords: Actual Structural Parameters, Integrated Structural Assessment Framework, Rebound Hammer Testing, Structural Reanalysis

1 Introduction

1.1 Necessity of Structural Assessment for Existing Buildings

Existing reinforced concrete (RC) buildings constitute a substantial part of the built infrastructure in many countries. Many of these buildings have been in service for decades and may continue to be used beyond their originally intended design service life. Population growth, urban development, and the increasing demand for sustainable

infrastructure have progressively shifted civil engineering practices toward the maintenance, rehabilitation, and service-life extension of existing buildings. Therefore, reliable structural assessment is essential to ensure their safety, functional adequacy, and long-term reliability. Consequently, assessments based solely on original design documents may not adequately represent the current condition of the structure, making field investigation and verification essential for evidence-based engineering decision-making (ISO 13822, 2010).

Structural assessment is also required when buildings undergo changes in function, renovation, vertical extensions, seismic retrofitting, or post-disaster evaluation. Before any intervention is undertaken, the capacity of the existing structure must be verified against its actual condition and the requirements of applicable standards (ACI Committee 562, 2021). The need for systematic assessment of existing structures has been recognized by international standards. ISO 13822:2010, *Bases for Design of Structures – Assessment of Existing Structures*, emphasizes the use of verified information to determine the actual condition of existing structures. Similarly, ACI 562-21. In Indonesia, the assessment of existing reinforced concrete structures should consider the provisions of SNI 2847:2019 for structural concrete, SNI 1727:2020 for minimum design loads, and SNI 1726:2019 for earthquake-resistant design. These standards provide the technical basis for verifying structural adequacy once representative structural parameters have been established through field investigation.

In many buildings, particularly residential buildings and small- to medium-scale structures, construction records, material test results, and quality-control documentation are often incomplete or unavailable. Consequently, the actual material properties may differ from those assumed in the original design. This uncertainty can be greater in site-mixed concrete, where strength is influenced by mix proportions, material characteristics, placing, compaction, curing, and construction quality control. Concrete compressive strength may also vary among structural elements due to differences in materials, construction practices, and environmental exposure. Therefore, using the design concrete compressive strength as the sole basis for assessment may produce an evaluation that does not adequately represent the actual condition or capacity of the structure.

These conditions demonstrate that reliable structural assessment requires verified information regarding the actual characteristics of the existing structure. Such information should be integrated into structural reanalysis to obtain a representative evaluation of structural capacity. Accordingly, this study introduces Actual Structural Parameters (ASP) as a representation of the verified condition of an existing structure and proposes an Integrated Structural Assessment Framework (ISAF) that systematically connects field investigation, determination of actual structural parameters, structural reanalysis, capacity assessment, and evidence-based engineering decision-making.

1.2 Concrete Strength as the Most Critical Structural Parameter

Concrete compressive strength is a key parameter governing the performance of reinforced concrete structures because it directly contributes to the flexural, axial, and shear capacity of structural elements, as well as their stiffness and serviceability.

Reliable determination of in-place concrete strength is therefore essential for the assessment of existing reinforced concrete buildings (ACI Committee 318, 2019; Neville, 2011). Variability is generally greater in site-mixed concrete because batching accuracy, mixing, placing, compaction, and curing are more dependent on field conditions and construction quality control (Mehta & Monteiro, 2014; Neville, 2011). Therefore, the actual concrete compressive strength in an existing building may differ from the value specified in the original design, particularly when construction records and material test results are incomplete or unavailable. Relying solely on design parameters may result in capacity estimates that do not adequately represent the current structural condition and may consequently affect the reliability of engineering decisions.

Structural assessment should therefore be based on Actual Structural Parameters (ASP) established and verified through field investigation. In addition to concrete compressive strength, ASP includes structural geometry, configuration, reinforcement detailing, and relevant physical conditions of the existing building. Within the proposed ISAF framework, these verified parameters are integrated into structural reanalysis to provide a representative assessment of structural capacity and support evidence-based engineering decision-making.

1.3 Research Gap

Various studies have applied Non-Destructive Testing (NDT) methods to assess existing reinforced concrete structures. Among these methods, Rebound Hammer Testing is widely used because it provides a rapid, economical, and non-destructive means of estimating the quality of in-place concrete (Malhotra & Carino, 2004). Previous studies have primarily focused on the relationship between rebound numbers and concrete compressive strength, while ACI 228.1R recognizes the Rebound Hammer as a method for estimating in-place concrete properties when supported by appropriate calibration and sound engineering judgment (ACI Committee 228, 2003). Breyse (2012) further demonstrated that Rebound Hammer results are influenced by material and environmental conditions, including moisture, carbonation, and testing procedures. Despite these contributions, most previous studies have treated the estimated concrete compressive strength as the endpoint of the investigation. Consequently, the integration of field investigation results into structural analysis to assess the actual capacity of existing buildings remains relatively limited. This creates a gap between material characterization and structural performance assessment, because concrete compressive strength alone cannot determine whether an existing structure can safely satisfy the applicable load demands.

To address this gap, this study proposes an Integrated Structural Assessment Framework (ISAF) that systematically transforms verified field investigation results into ASP, incorporates them into structural reanalysis, and uses the resulting analytical outcomes to support structural capacity assessment and evidence-based engineering decision-making. Accordingly, Rebound Hammer Testing is positioned not as the endpoint of the investigation, but as an initial component of an integrated structural assessment process. Its results are transformed into verified structural information that directly contributes to capacity evaluation and engineering decision-making. The

conceptual distinction between the conventional approach and the proposed ISAF is illustrated in Figure 1.

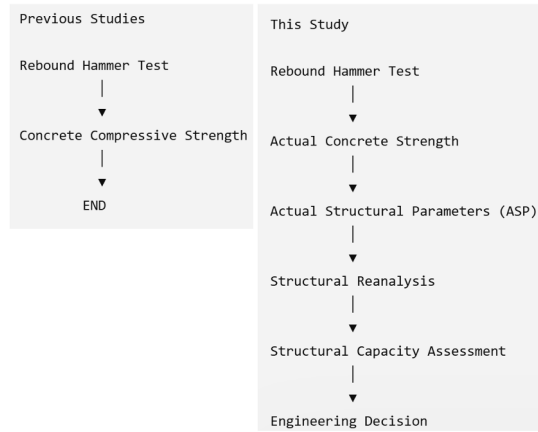


Figure 1. Comparison Between the Conventional Application of the Rebound Hammer Test and the Proposed Integrated Structural Assessment Framework (ISAF).

Previous studies have demonstrated the capability of Rebound Hammer Testing to estimate concrete compressive strength. However, its integration into structural reanalysis for engineering decision-making remains limited. The novelty of this study does not lie in the application of Rebound Hammer Testing itself, but in the development of the Integrated Structural Assessment Framework (ISAF), which transforms verified field investigation results into Actual Structural Parameters (ASP) and integrates them into structural reanalysis to support evidence-based assessment and engineering decision-making for existing reinforced concrete buildings.

1.4 Research Objective

Based on the identified research gap, this study aims to develop and validate an Integrated Structural Assessment Framework (ISAF) that integrates field investigation with structural reanalysis to improve the reliability of assessing existing reinforced concrete buildings. The specific objectives are to:

- 1) Determine the actual concrete compressive strength of the existing reinforced concrete building using the Rebound Hammer Test as a source of verified field-investigation data.
- 2) Establish the Actual Structural Parameters (ASP) by integrating the verified concrete compressive strength with other structural characteristics representing the actual condition of the building.
- 3) Perform structural reanalysis and capacity assessment based on the established ASP in accordance with SNI 2847:2019 to verify the adequacy of the existing structure.
- 4) Demonstrate the application of ISAF in transforming verified field-investigation results into evidence-based engineering decisions.

1.5 Research Novelty

The novelty of this study lies not in the application of the Rebound Hammer Test, which has been widely used to estimate concrete compressive strength in existing structures, but in the development of an Integrated Structural Assessment Framework (ISAF) that transforms verified field-investigation results into engineering information for structural assessment.

Within ISAF, the investigated concrete compressive strength is not treated as the endpoint of the investigation. Instead, it forms part of the Actual Structural Parameters (ASP) together with structural geometry, reinforcement details, structural configuration, and relevant physical conditions. The verified ASP are subsequently incorporated into structural reanalysis and capacity assessment to support evidence-based engineering decision-making.

The contributions of this study can be viewed from conceptual, methodological, and practical perspectives. Conceptually, the study introduces Actual Structural Parameters (ASP) as a set of verified structural information representing the actual condition of an existing building. Methodologically, it develops the Integrated Structural Assessment Framework (ISAF), which systematically integrates field investigation, ASP establishment, structural reanalysis, capacity assessment, and engineering decision-making into a unified assessment process. Practically, the proposed framework provides an evidence-based engineering procedure for assessing the adequacy of existing reinforced concrete structures and supporting decisions regarding continued service, rehabilitation, and structural strengthening (retrofitting).

1.6 Research Conceptual Framework

The proposed Integrated Structural Assessment Framework (ISAF) provides the conceptual basis of this study by integrating field investigation and structural reanalysis to support evidence-based engineering decision-making for existing reinforced concrete buildings. Unlike conventional practice, in which the Rebound Hammer Test is primarily used to estimate concrete compressive strength, ISAF positions the test as an initial component of establishing verified Actual Structural Parameters (ASP). As illustrated in Figure 2, field investigation combines Non-Destructive Testing (NDT) with structural examination to obtain verified information on concrete compressive strength, structural geometry, reinforcement details, structural configuration, and relevant physical conditions.

These data are synthesized into ASP and incorporated into structural reanalysis in accordance with SNI 2847:2019, followed by structural capacity assessment and engineering decision-making. Thus, ISAF establishes a systematic and traceable workflow from field investigation to engineering decision-making, ensuring that structural assessment is based on verified information representing the actual condition of the existing building rather than solely on assumed design parameters

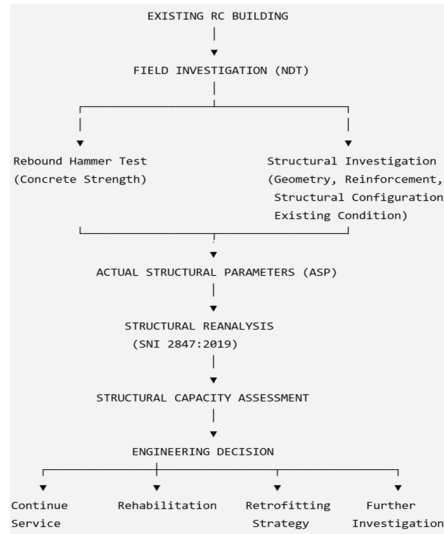


Figure 2. Integrated Structural Assessment Framework (ISAF)

2 Methodology

2.1 Research Methodology Overview

This study employs a quantitative engineering approach that integrates field investigation using Rebound Hammer Testing with structural reanalysis. Rather than treating the estimated concrete compressive strength as the final outcome of the investigation, verified field data are incorporated into the Actual Structural Parameters (ASP) to assess the capacity of the existing reinforced concrete building. The methodology is based on the principle that the assessment of existing structures should reflect their actual condition rather than relying solely on parameters assumed in the original design, in accordance with the principles outlined in ISO 13822 and ACI 562 (ISO, 2010; ACI Committee 562, 2021). Accordingly, field investigation, material characterization, determination of actual structural parameters, structural reanalysis, and capacity assessment are integrated into a unified assessment procedure.

The research consists of six sequential stages: (1) identification of the case-study building; (2) field investigation using Rebound Hammer Testing; (3) data processing and determination of the actual concrete compressive strength; (4) establishment of the Actual Structural Parameters (ASP); (5) structural reanalysis in accordance with SNI 2847:2019; and (6) structural capacity assessment as the basis for engineering decision-making.

2.2 Research Framework

The proposed methodology is developed based on the principles of Performance-Based Assessment, in which the assessment of existing structures should rely on actual

structural parameters obtained through field investigation rather than solely on the assumptions adopted in the original design (ACI Committee 562, 2021; ISO, 2010).

In this study, Rebound Hammer Testing is used to determine a key material parameter, namely the actual concrete compressive strength. This parameter is combined with verified information on structural geometry, configuration, and reinforcement detailing to establish the Actual Structural Parameters (ASP) used in the structural reanalysis.

2.3 Case Study Building and Field Investigation

The case study was conducted on a three-story reinforced concrete residential building located in Tabanan Regency, Bali, Indonesia. The building was selected because documentation of concrete quality during construction was unavailable, necessitating a structural assessment to verify its load-bearing capacity. Non-Destructive Testing (NDT) was employed to obtain information on the in-place condition of the concrete without damaging the structural elements (Breysse, 2012). The structural system consists of reinforced concrete columns, beams, and slabs serving as the primary gravity load-carrying elements.

The field investigation was conducted using Rebound Hammer Testing in accordance with ASTM C805/C805M-23 (ASTM International, 2023). The investigation covered reinforced concrete columns, beams, and slabs distributed throughout the building. A total of 80 test locations were selected to obtain representative information on the in-place concrete condition. At each test location, 30 impacts were performed, resulting in a total of 2,400 rebound number measurements. The relatively large number of impacts was intended to reduce the influence of local surface variability and improve the statistical reliability of the measurements (ASTM International, 2023; Breysse, 2012).

Table 1. Distribution of Rebound Hammer Test Locations

Structural Element	Number of Test Location	Impacts per Test Location	Total Impacts
Columns (Level 1)	35	30	1,050
Beams (Level 2)	16	30	480
Slabs (Level 2)	12	30	360
Beams (Level 3)	8	30	240
Slabs (Level 3)	9	30	270
Total	80	30	2,400

The 80 test locations comprised 35 columns, 24 beams, and 21 slabs distributed across the three-story building. The resulting dataset was used for statistical processing and subsequent determination of the actual concrete compressive strength as an input to the Actual Structural Parameters (ASP).

2.4 Data Processing and Structural Reanalysis Setup

The rebound numbers obtained at each test location were statistically processed to determine a representative rebound number for each location. The representative

rebound number was then converted into the characteristic cube compressive strength of the concrete using the calibration curve provided by the Rebound Hammer manufacturer. The cube compressive strength was subsequently converted into an equivalent cylinder compressive strength using a conversion factor of 0.83, in accordance with SNI 03-1974-1990, which adopts an empirical relationship from PBI 1971. This approach was adopted because SNI 2847:2019 does not provide a specific conversion procedure between cube and cylinder compressive strengths.

3 Result and Discussion

3.1 Rebound Hammer Test Investigation Results

Test Rebound Hammer Testing was conducted to assess the in-place concrete quality of the existing three-story reinforced concrete residential building. The investigation covered 80 test locations, consisting of 35 columns, 24 beams, and 21 slabs, with 30 impacts recorded at each location in accordance with ASTM C805/C805M-23, resulting in a total of 2,400 rebound number measurements. The results showed noticeable variations in rebound numbers among the structural elements, reflecting the inherent variability of in-place concrete quality in existing buildings. This variability may be attributed to differences in constituent materials, concrete production and placement, compaction, curing, and environmental exposure throughout the service life of the structure (Malhotra & Carino, 2004; Neville, 2011). The processed rebound numbers were converted into estimates of the characteristic cube compressive strength using the calibration curve provided by the Rebound Hammer manufacturer. The results are summarized in Table 2.

Table 2. Summary of Rebound Hammer Test Results

Structural Element	No. of Test Location	Impacts per Test Location	Minimum Rebound Number	Maximum Rebound Number	Estimated Characteristic Cube Strength, (f'_{ck}) (kg/cm ²)
Columns (Level 1)	35	30	20.18	39.91	280.33
Beams (Level 2)	16	30	27.37	43.10	245.19
Slabs (Level 2)	12	30	35.06	44.24	288.75
Beams (Level 3)	8	30	29.07	39.49	234.15
Slabs (Level 3)	9	30	34.67	42.51	266.10

The estimated characteristic cube compressive strength ranged from 234.15 to 288.75 kg/cm². The highest value was obtained for the second-floor slab (288.75 kg/cm²), while the lowest value was recorded for the third-floor beam (234.15 kg/cm²). This variation confirms that the in-place concrete quality was not uniform across the investigated structural elements.

3.2 Determination of Actual Concrete Strength

The lowest value was obtained for the third-floor beam, with an estimated characteristic cube compressive strength of 234.15 kg/cm² at an equivalent age of 28 days. After

conversion, the corresponding equivalent cylinder compressive strength was 194.35 kg/cm², or 19.43 MPa. For a conservative structural assessment, this minimum value of 19.43 MPa was adopted as the reference concrete compressive strength in the structural reanalysis.

Table 3. Determination of Equivalent Cylinder Compressive Strength for Structural Reanalysis

Structural Element	Estimated Cube Strength, (f'ck) (kg/cm ²)	Equivalent Cylinder Strength, (f'c) (kg/cm ²)	Equivalent Cylinder Strength, (f'c) (MPa)
Columns	280.33	232.67	23.27
Beams (Level 2)	245.19	203.50	20.35
Slabs (Level 2)	288.75	239.67	23.97
Beams (Level 3)	234.15	194.35	19.43
Slabs (Level 3)	266.10	220.86	22.09

Note: The lowest equivalent cylinder compressive strength obtained from the field investigation

was 19.43 MPa. For structural reanalysis, this value was conservatively rounded down to f'c = 19 MPa based on engineering judgment.

3.3 Transformation of Hammer Test Results into Actual Structural Parameters

In this study, the minimum equivalent cylinder compressive strength of 19 MPa was adopted as the primary material parameter for structural reanalysis. This value was integrated with the actual structural geometry, element configuration, and reinforcement information obtained from construction drawings and field observations to establish the parameters used in the analytical model. Unlike the design of new buildings, which relies heavily on specified material properties and assumed design parameters, the assessment of existing buildings requires material and structural information that reflects verified field conditions. Integrating these parameters into the analytical model enables the reanalysis to represent the actual structural condition more accurately than an assessment based solely on the assumptions adopted in the original design.

3.4 Results and Evaluation of Structural Reanalysis

Following the establishment of the Actual Structural Parameters (ASP), structural reanalysis was conducted to evaluate the performance of the existing reinforced concrete residential building using the material and structural information obtained from the field investigation. Structural analysis and element capacity verification were performed in accordance with SNI 2847:2019, which is based on the principles of ACI 318-19.

Table 4. Summary of Structural Reanalysis Results

Structural Member	Evaluation Parameter	Analysis Result
Columns	Longitudinal reinforcement ratio	1.30–2.67%
	Required shear reinforcement (support region)	1.485 mm ² /mm

Beams	Required shear reinforcement (span region)	0.301 mm ² /mm
	Overstressed members	None
	Oversized members	None
	Required shear reinforcement (support region)	1.358 mm ² /mm
	Required shear reinforcement (span region)	0.105 mm ² /mm
	Overstressed members	None
	Oversized members	None

The reanalysis indicates that the existing reinforced concrete building has adequate structural capacity under the evaluated loading conditions, even when a conservative concrete compressive strength of $f'_c = 19$ MPa is adopted. No structural elements were identified as overstressed, and the required reinforcement remained within the limits specified by SNI 2847:2019. The absence of oversized elements also indicates that the dimensions of the existing structural elements remain proportional to the verified material properties and the structural load demands.

3.5 Engineering Synthesis and Decision-Making

The key finding of this study is that the practical value of Rebound Hammer Testing extends beyond the estimation of concrete compressive strength. The verified material properties are transformed into Actual Structural Parameters (ASP) and incorporated into element capacity calculations through the proposed Integrated Structural Assessment Framework (ISAF).

Table 5. Engineering Assessment Based on Structural Reanalysis

Evaluation Aspect	Verified Result	Engineering Assessment
Concrete compressive strength	(f'_c) = 19 MPa	Conservative verified material property for structural analysis
Structural model	Actual geometry, reinforcement, and structural configuration	Represents the verified structural condition
Column performance	No overstressed members	Columns satisfy strength requirements
Beam performance	No overstressed members	Beams satisfy strength requirements
Longitudinal reinforcement ratio	Within SNI design limits	Reinforcement is structurally adequate
Shear reinforcement demand	Within SNI requirements	Adequate shear resistance
Overall structural performance	Satisfies structural verification	Building is structurally adequate

Table 6. Transformation of Structural Assessment into Engineering Decision

Assessment Criterion	Verification Result	Engineering Decision
Actual concrete strength	Verified by Rebound Hammer Test	Accepted as Actual Structural Parameter
Structural capacity	Adequate	Structure is adequate
Structural stability	Satisfies SNI requirements	Structure is Stable
Reinforcement efficiency	Within code limits	Reinforcement is adequate
Overall structural performance	Meets all evaluation criteria	Continued service is recommended

Table 7. Engineering Verification Matrix of the Proposed Integrated Structural Assessment Framework (ISAF)

Assessment Aspect	Verification Method	Engineering Evidence	Verification Status
Actual concrete strength	Rebound Hammer Test	Verified concrete compressive strength	Accepted
Structural model	Field investigation and structural survey	Verified geometry, reinforcement, and structural configuration	Accepted
Column capacity	Structural reanalysis	No overstressed members identified	Verified
Beam capacity	Structural reanalysis	No overstressed members identified	Verified
Shear capacity	Structural reanalysis	Shear reinforcement satisfies SNI requirements	Verified
Reinforcement efficiency	Structural reanalysis	Reinforcement ratio within SNI limits	Verified
Overall structural reliability	Integrated structural assessment	All verification criteria satisfied	Acceptable

Table 8. Engineering Decision Matrix Based on the Proposed Integrated Structural Assessment Framework (ISAF)

Engineering Criterion	Verification Result	Engineering Basis
Structural strength	Satisfied	No overstressed structural members
Structural stability	Satisfied	Structural verification in accordance with SNI 2847:2019
Serviceability	Acceptable	Structural reanalysis under the prescribed loading conditions
Structural efficiency	Satisfied	No oversized members; reinforcement within code requirements
Overall structural condition	Structurally adequate	Integrated Structural Assessment Framework (ISAF)

Table 9. Comparison Between the Conventional Structural Assessment Approach and the Proposed Integrated Structural Assessment Framework (ISAF)

Assessment Aspect	Conventional Approach	Proposed ISAF
Role of the Rebound Hammer Test	Material characterization	Initial stage of integrated structural assessment
Structural parameters	Primarily based on available design information	Verified Actual Structural Parameters (ASP)
Structural analysis	May be conducted separately from field investigation	Directly linked to verified field information
Structural capacity assessment	Conducted as a separate assessment stage	Integrated within the assessment framework
Final engineering output	Material characterization and/or structural assessment	Structural adequacy assessment and traceable engineering decision

4 Conclusion

This study proposes an Integrated Structural Assessment Framework (ISAF) for assessing existing reinforced concrete buildings by integrating Rebound Hammer Test results into Actual Structural Parameters (ASP) and structural reanalysis. This study proposes an Integrated Structural Assessment Framework (ISAF) for assessing existing reinforced concrete buildings by integrating Rebound Hammer Test results into Actual Structural Parameters (ASP) and structural reanalysis. The results demonstrate that Rebound Hammer Testing provides verified information on concrete compressive strength that can be transformed into ASP for structural reanalysis. The proposed ISAF successfully integrates field investigation, ASP establishment, structural reanalysis, capacity assessment, and engineering decision-making into a unified assessment process. Structural reanalysis using the established ASP, with a concrete compressive strength of $f_c = 19$ MPa, demonstrated compliance with SNI 2847:2019, with no structural elements identified as overstressed. Overall, the ISAF establishes a systematic link between field-based evidence and engineering decisions, providing a basis for recommendations regarding the continued use of the existing building.

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