Jurnal Teknik Indonesia

Volume 5 Nomor 3 August 2026

https://jti.publicascientificsolution.com/index.php/rp

Evaluation of the Structural Performance of the Tunas Building at Gunung Jati University Using the Forensic Audit Method and Non-Destructive Testing (NDT)

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Keywords:

non-destructive test; rebound hammer; ultrasonic pulse velocity; forensic structural audit; ETABS; reinforced concrete column

Abstract

Educational buildings must maintain structural reliability throughout their service life, particularly as usage intensity and functional demands increase over time. The Tunas Building of the Faculty of Engineering, Universitas Gunung Jati, requires an objective, field-based structural evaluation rather than an assessment based solely on original design assumptions. This study aimed to evaluate the structural performance of reinforced concrete columns through an integrated forensic audit approach using non-destructive testing (NDT) and numerical structural analysis. A quantitative evaluative approach was applied to 36 columns selected through purposive sampling. Visual inspections were conducted to identify surface defects, followed by Schmidt Rebound Hammer testing (ASTM C805) to estimate concrete compressive strength and Ultrasonic Pulse Velocity (UPV) testing (ASTM C597) to assess internal concrete quality. The relationship between the two NDT methods was analyzed using Pearson correlation, while structural capacity was evaluated through ETABS modeling based on SNI 2847:2019, SNI 1727:2020, and SNI 1726:2019. The results showed minor hairline cracks and localized honeycombing in a limited number of columns. Rebound Hammer testing produced an average estimated compressive strength of 37.2 MPa, ranging from 32–40 MPa, which met the minimum requirements for structural concrete. UPV testing classified 97.22% of measurement points as "Good" and 2.78% as "Very Poor." Pearson correlation analysis indicated a significant positive relationship between the two testing methods ($r = 0.489$; $p = 0.002$). ETABS Design Check results showed that 35 of 36 columns (97.22%) met the required strength criteria, while one column (2.78%) did not satisfy the requirements. Overall, the existing structure remained structurally adequate for service, although the failed column required further investigation and potential strengthening measures

Introduction

Educational buildings serve as public facilities that must meet safety, comfort, and structural reliability requirements throughout their service life. In this context, the Tunas Engineering Building of Universitas Gunung Jati plays a strategic role as a center for academic, laboratory, and engineering learning activities that require strong and stable structural conditions. The reliability of existing building structures is essential considering the high intensity of space utilization and the potential increase in structural loads due to functional

modifications, laboratory equipment, and additional users over time (Atef et al., 2024; Chen et al., 2020). Without adequate structural evaluation, material degradation, such as reduced concrete quality, reinforcement corrosion, and microcracking, may develop into serious problems affecting user safety and the continuity of building functions (YU et al., 2024).

The evaluation of existing structures needs to be conducted objectively based on actual field conditions rather than relying solely on initial design assumptions (West et al., 2024). A structural forensic audit approach based on Non-Destructive Testing (NDT) is an appropriate method because it provides technical information regarding material quality and structural integrity without damaging reinforced concrete elements. The three primary methods used in this study, namely Visual Inspection, Rebound Hammer Testing, and Ultrasonic Pulse Velocity (UPV) testing, serve complementary purposes. Rebound Hammer Testing estimates concrete compressive strength (f'c), UPV testing measures ultrasonic wave propagation velocity to evaluate internal defects and material uniformity, and Visual Inspection identifies surface conditions and early indications of structural damage (Arora et al., 2024; Prahmana, 2012; Wu et al., 2026). The combination of these methods provides a comprehensive assessment of structural quality, homogeneity, and integrity, which is essential for evaluating the condition of actively used buildings such as faculty facilities (Abdollahi-Mamoudan et al., 2025; Kusyi et al., 2026).

The advantage of the NDT method compared with Destructive Testing (DT) lies in its non-invasive and efficient characteristics. Testing can be conducted without significantly disrupting building activities, making it suitable for educational facilities that remain operational (Adriana, 2016; Darmawan, 2016). Furthermore, NDT data can be integrated with structural capacity analysis based on technical standards, such as SNI 2847:2019 (Structural Concrete Requirements for Buildings) and SNI 1726:2019 (Earthquake Resistance Planning Standards for Building and Non-Building Structures), to quantitatively evaluate structural safety and serviceability.

Previous studies have shown that the application of NDT-based forensic audits in Indonesia remains predominantly reactive, with evaluations often conducted after damage or structural problems occur. Efendi and Maret (n.d.) applied forensic audit methods at the Samarinda Mother and Child Hospital to investigate foundation settlement, while Hermansyah (2025) evaluated the Kutai Kartanegara Bappeda Building, which exhibited cracking and foundation degradation. Wahyudi Efendi et al. (2023) examined concrete quality in existing buildings in Semarang, while Enggartiasto et al. (2023) investigated damage identification and concrete conditions using NDT approaches. Although these studies demonstrated the reliability of NDT-based assessments, most focused primarily on damage identification or material quality evaluation rather than integrating NDT results with structural capacity analysis based on national standards (Azimi et al., 2020; Gupta et al., 2021). This indicates the need for a more comprehensive preventive evaluation approach that combines material assessment, structural analysis, and compliance evaluation with applicable regulations (Supardi, 2015).

The urgency of this research is supported by the strategic importance of educational buildings and the increasing demands placed on their structural performance due to changing functional requirements. The Tunas Engineering Building serves as a center for engineering education activities, accommodating laboratory equipment and significant occupant loads, which require continuous evaluation of structural integrity. Without systematic assessment,

potential material deterioration or structural deficiencies may compromise safety and result in higher rehabilitation costs if not addressed promptly. The integration of forensic audit principles, emphasizing systematic evidence collection and root-cause analysis, with NDT methods provides a comprehensive framework for evaluating existing structures in accordance with international practices in structural forensics (Rus et al., 2024).

Based on this context, this study adopts a preventive and evaluative approach rather than a reactive one. The main objective is to assess the structural performance of the Tunas Engineering Building at Universitas Gunung Jati by integrating forensic audit methods and NDT results to determine concrete quality, structural element integrity, and compliance with applicable SNI standards. This approach is expected to provide a comprehensive evaluation of the reliability and serviceability of educational buildings as public facilities, while also providing a scientific basis for technical decision-making related to future maintenance, strengthening, and rehabilitation strategies.

Methods

Population and Sample

The population of this study consisted of the main structural elements of the Tunas Engineering Building, Gunung Jati University, including columns and floors at all building levels. These elements were evaluated as the primary components responsible for carrying gravitational and lateral loads in assessing structural performance.

Considering the extensive scope of structural elements and the limitations of field testing time and efficiency, this study applied a structural zoning-based purposive sampling technique. The test locations were selected based on technical considerations relevant to the evaluation of existing building conditions rather than through random sampling.

Data Analysis Techniques

The data analysis was conducted systematically to process field test results into structural performance indicators that were evaluated against applicable technical standards.

Results and Discussion

Structural Modeling Results Using ETABS

Building Structure Modeling

After visual inspection, *Hammer Test*, and *Ultrasonic Pulse Velocity* (UPV) testing, the next stage is to evaluate the performance of the structure using ETABS v22 software. Structural modeling is carried out to determine *the* response of the building to the working load and evaluate the behavior of the structure based on the existing conditions of the building.

The structure model was made based on the actual condition of the Tunas Engineering Building of Gunung Jati University which consists of three floors and one roof. The modeled structural elements include columns, beams, and reinforced concrete slabs. The dimensions of structural elements are obtained from the results of field measurements so that the model made can represent the actual condition of the building.

The building is modeled as a reinforced concrete frame structure with a height of 3 meters on each floor. Structural analysis was carried out by considering dead loads, live loads, and earthquake loads based on the provisions of SNI 1726:2019.

Table 1 Building Structure Modeling Data

Parameter	Remarks
Building Name	Tunas Engineering Building, Gunung Jati University
Building Function	Education Building
Number of Floors	3 Floors + Roof
Height of Each Floor	3 m
Structural Systems	Reinforced Concrete Frame
Software	ETABS v22
Building Location	Cirebon City, West Java
Earthquake Analysis Method	*Response Spectrum*
Reference Standards	SNI 1726:2019 and SNI 2847:2019

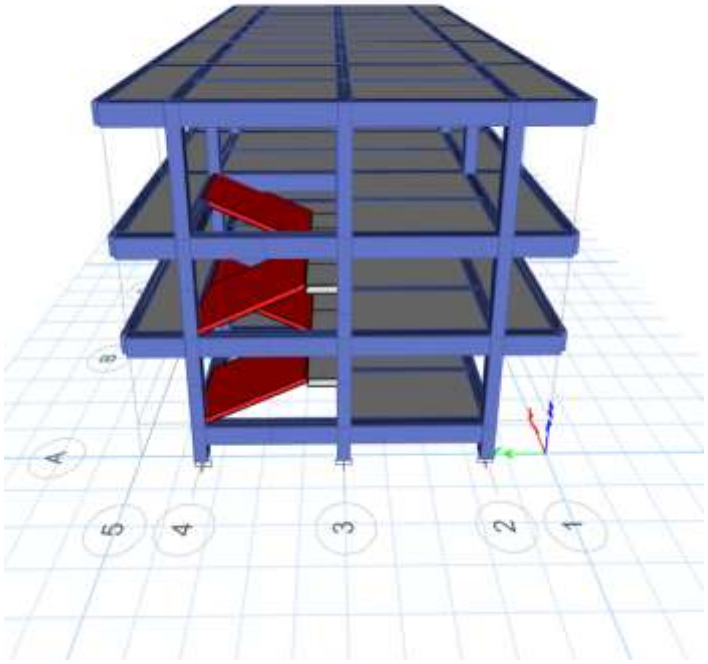

Figure 1 Perspective of Existing Building Structures and Stair Systems

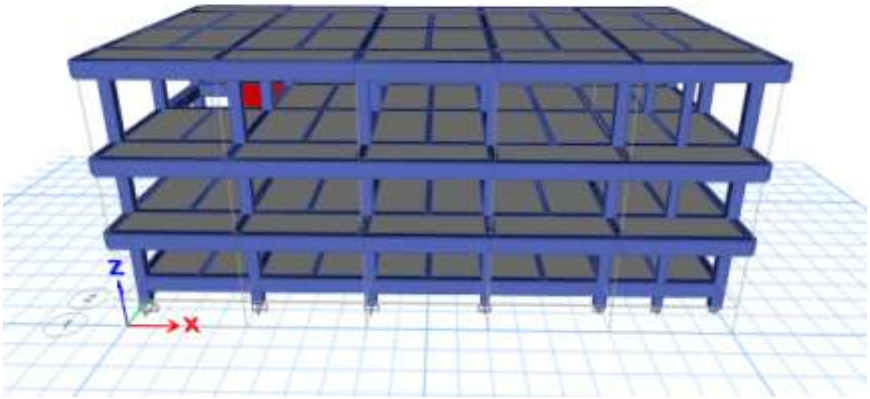

Figure 2 Side View of Existing Building Structure

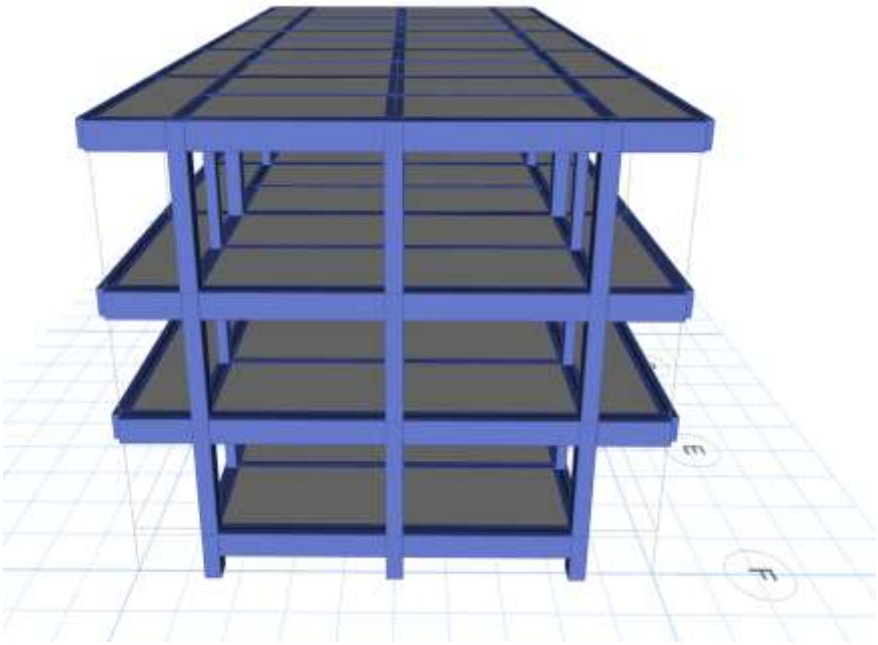

Figure 3 Front View of Existing Building Structure

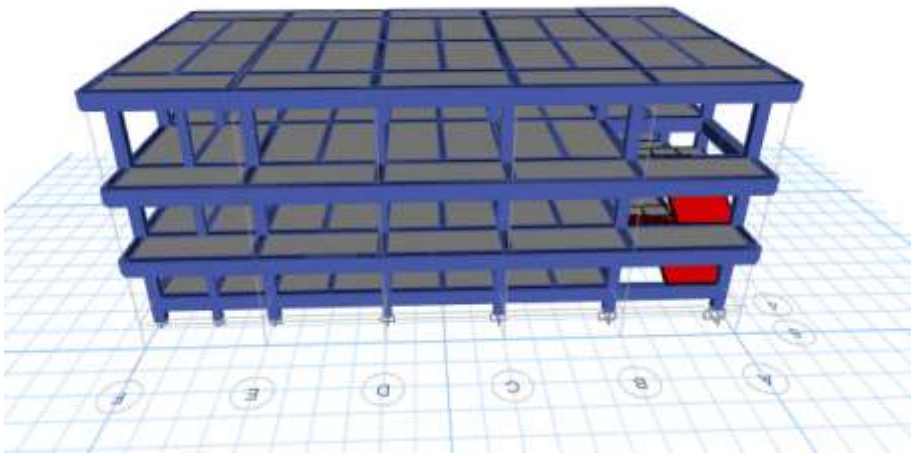

Figure 4 Back View of Existing Building Structure

Material Input Based on Hammer Test Results

The concrete material data used in the ETABS modeling was obtained from the results of *the Hammer Test* on 36 reinforced concrete columns. The test yields equivalent compressive strength (fc') values of concrete that vary between 32 MPa to 40 MPa.

The use of the compressive strength value of the concrete from the field test aims to make the structural analysis reflect the actual condition of the existing building. The quality value of the concrete obtained shows that the concrete in the column elements is still in the good category and meets the requirements as structural concrete.

Table 2 Concrete Quality Based on Results Hammer Test

Parameter	Value
Minimum Concrete Quality	32 MPa
Maximum Concrete Quality	40 MPa
Dominant Concrete Quality	36 MPa

Based on these results, the concrete material in the ETABS model was defined using concrete quality according to the results of field tests. Thus, the analysis carried out is able to describe the behavior of the structure more realistically than using the assumption of the quality of planning concrete.

The analysis of the compressive strength value of the concrete obtained shows that the quality of existing concrete is still in the good category. The quality of the concrete indicates that the structural elements still have sufficient compressive capacity to support the building's function as an educational building.



Figure 5 Concrete Material Input fc' 32 on ETABS

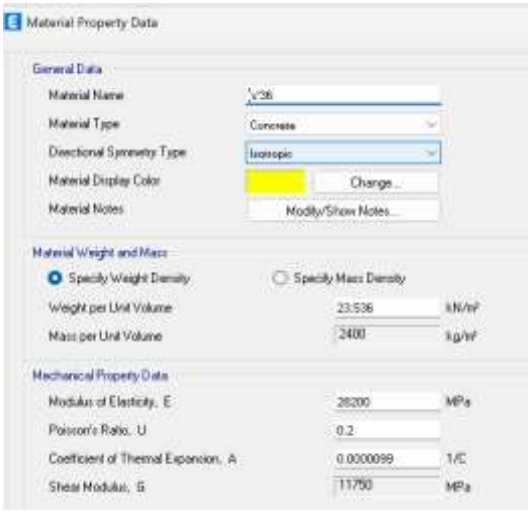

Figure 6 Concrete Material Input fc'36 on ETABS

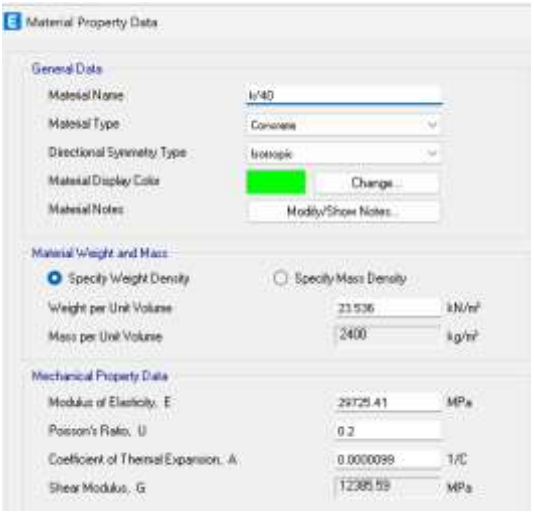

Figure 7 Concrete Material Input fc'40 on ETABS

Structural Load

The load on the structural model refers to the provisions of SNI 1727:2020 concerning the Minimum Load for the Design of Buildings and Other Structures and SNI 1726:2019 for earthquake loads.

The types of loads used in the analysis include *Dead Load*, Super *Dead Load*, Live Load, and Earthquake *Load*.

a. Dead Load

The dead load is the weight of the structural element itself which is automatically calculated by the ETABS program based on the dimensions and specific gravity of the material used.

b. Super *Dead Load*

Additional dead loads include floor covering loads, ceilings, mechanical and electrical installations, and other permanent building components.

The value of the additional dead load used is as follows:

SDL = 1.50 kN/m2

SDL = 1.50 \, kN/m^2

SDL = 1.50kN/m2

c. Live Load

The living load used refers to the function of the building as an educational building.

Table 3 Building Life Load

Elements	Living Burden
1–3rd Floors	1.36 kN/m²
Roof	0.96 kN/m²

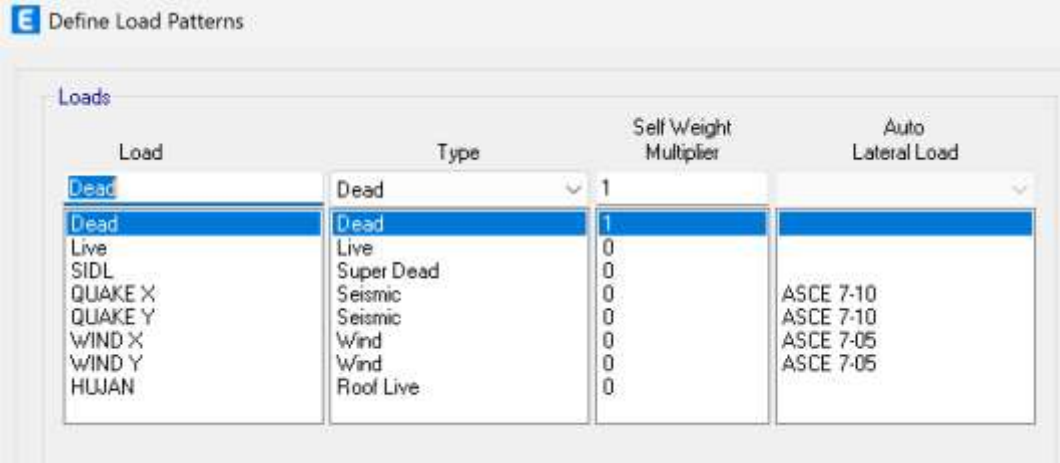

Figure 8 Load Inputs on ETABS

Spectrum Response *Analysis*

Earthquake analysis was carried out using the Spectrum Response method in accordance with the provisions of SNI 1726:2019. Spectrum parameters are obtained from the Indonesian Spectral Design application based on the location of the Tunas Engineering Building of Gunung Jati University in Cirebon City.

The class of site used is SB (Rock) because the soil condition at the research site is categorized as rock or hard soil.

Table 4 Parameter Response Spectrum Cirebon City

Parameter	Value
PGA	0.358 g
SS	0.786 g
S1	0.352 g
SDS	0.470 g
SD1	0.190 g
T0	0.080 seconds
Ts	0.400 seconds
TL	20 seconds
Site Class	SB

These parameters are used as the basis in the formation of *spectrum response* curves which are further applied to structural dynamic analysis using ETABS.

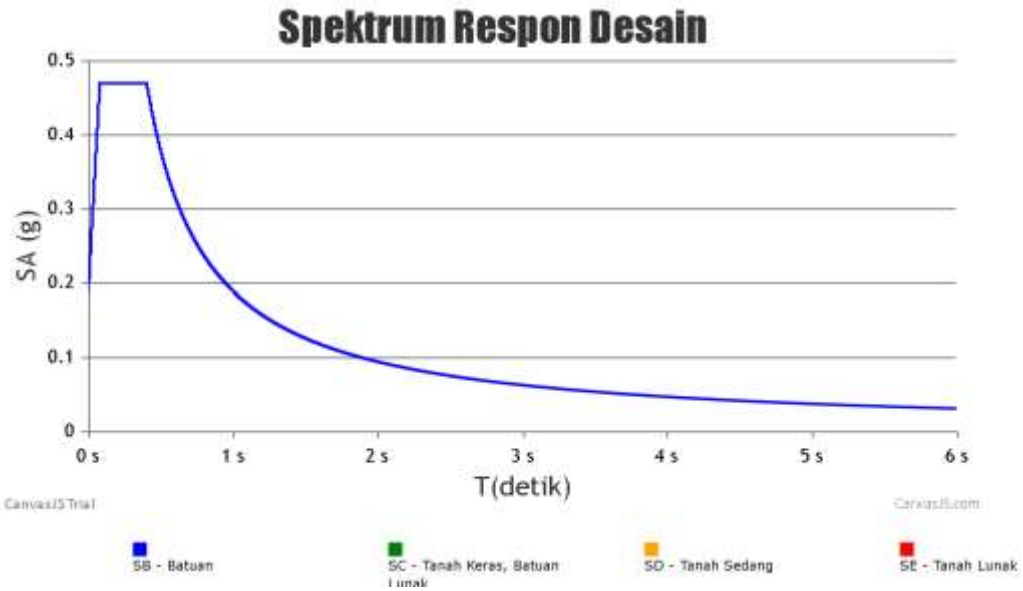

Figure 9 Curve Response Spectrum Cirebon City

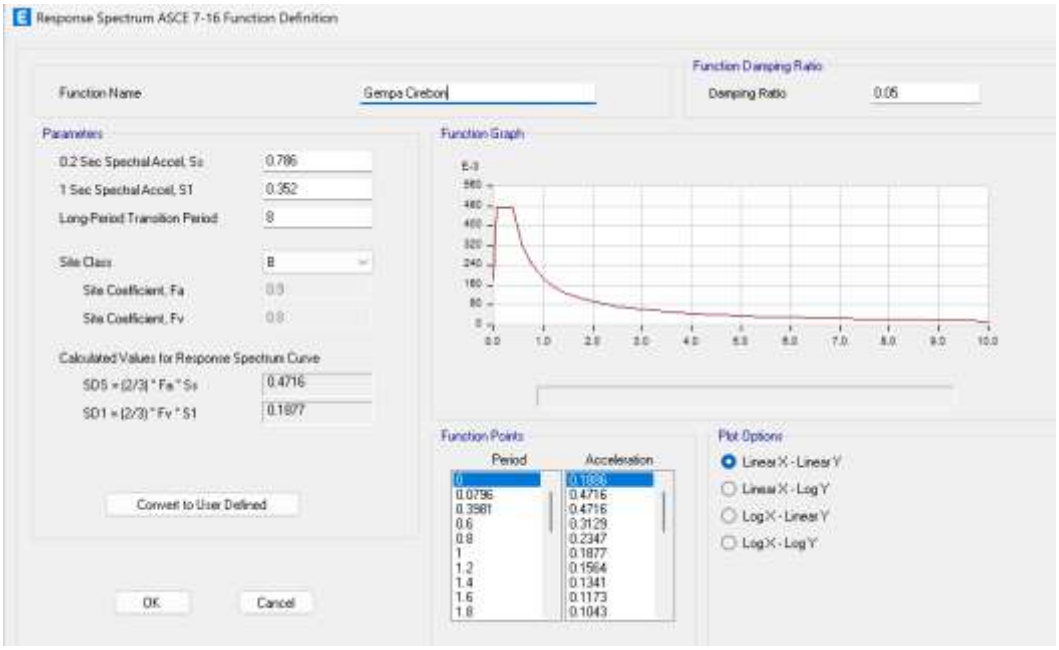

Figure 10 Input Response Spectrum on ETABS

The results of the spectrum response analysis showed that the structure was evaluated on the influence of the planned earthquake according to the seismic conditions of the Cirebon City area. The use of the spectrum response method allows for a more representative distribution of earthquake forces than the equivalent static method because it takes into account the dynamic characteristics of the structure.

The SDS value of 0.4716 g and SD1 of 0.1877 g showed that the study area had a moderate level of seismic activity so that the influence of earthquakes needed to be taken into account in the evaluation of the performance of the building structure.

Based on the spectrum parameters used, the structure is then analyzed to obtain responses in the form of vibration periods, deviations between floors (*story drift*), deflection, internal force, and evaluation of the capacity of structural elements which will be discussed in the next subchapter.

Hasil Run Analysis ETABS

After all stages of structural modeling are completed, including defining the building geometry, material input based on *the results of the Schmidt Rebound Hammer* test, defining the cross-sectional of structural elements, gravity loading, combination loading, and earthquake loading using the *Spectrum Response method* in accordance with SNI 1726:2019, then *a Run Analysis process* is carried out using ETABS v22 software.

The analysis process aims to obtain a structural response to a predetermined combination of loads. Through this process, ETABS calculates the rigidity of the structure, mass distribution, internal force, displacement, inter-floor deviation (*story drift*), convergence reaction, and checks the capacity of structural elements based on the material parameters that have been entered.

The results of the analysis show that the *Run Analysis* process was successfully completed without showing any modeling errors (*analysis errors*), structural instability (*instability*), or connectivity failures between elements (*connectivity error*). This shows that the structural model has met the requirements for further evaluation.

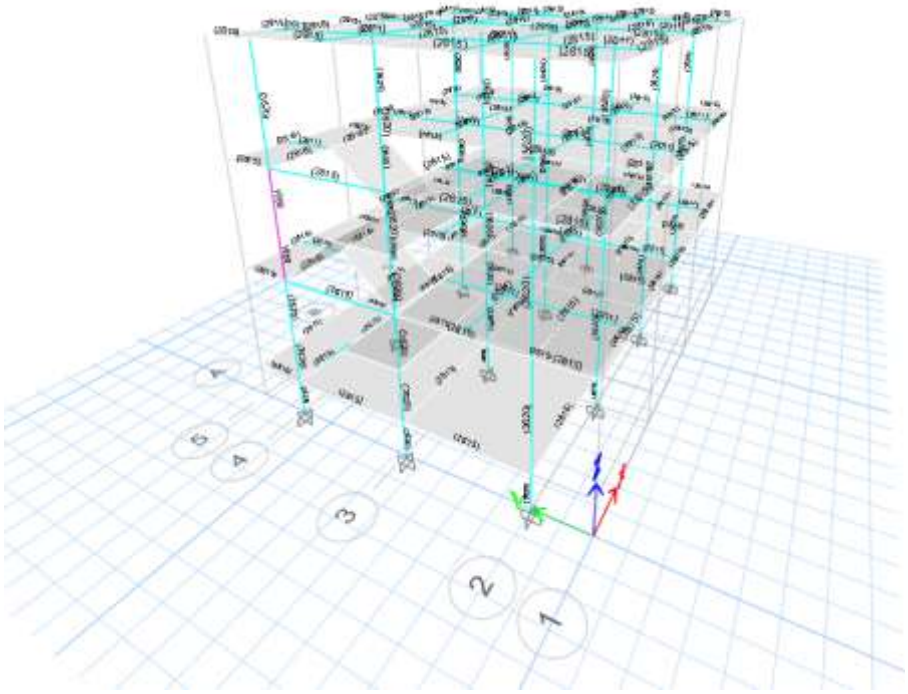

Figure 11 Results Run Analysis and Design Check Structure Using ETABS

Based on the results of the *design check*, most of the structural elements show a safe condition with a blue indicator indicating that the capacity of the elements is still able to withstand the load according to the combination of loads analyzed. However, there is one element in column 1 on the 2nd floor which is shown with a red indicator, which indicates that the element does not meet the requirements for structural capacity (*failed*) based on the results of the ETAB evaluation.

This condition indicates that the column capacity at the location is smaller than the working inner force so that the capacity-to-load ratio has exceeded the permissible limit. These

results do not necessarily indicate that the building is failing as a whole, but it does indicate the presence of critical elements that require special attention and further evaluation.

The existence of elements that do not meet the requirements can be influenced by several factors, including the decrease in concrete quality based on the results of field tests, cross-sectional dimensions that are relatively limited to the accepted load, force concentration due to structural configuration, and the combination of earthquake loading that results in greater capacity demands on these elements.

This finding is one of the important indicators in the study because the main purpose of the study is to evaluate the condition of the existing structure based on the results of *the Non-Destructive Test* (NDT) test and numerical analysis using ETABS.

The discussion was carried out to interpret the results of *the Non-Destructive Test* (NDT) which included visual inspection, *Schmidt Rebound Hammer*, and *Ultrasonic Pulse Velocity* (UPV) on the existing concrete conditions in the column structure elements of the Tunas Building, Faculty of Engineering, Gunung Jati University. This discussion aims to determine the level of compatibility between the results of field tests and theories regarding concrete quality, concrete internal integrity, and the feasibility of structural elements based on non-destructive testing methods.

Schmidt Rebound Hammer Results Discussion

The results of the test using *the Schmidt Rebound Hammer* showed that the estimated compressive strength of the concrete in the column element was in the range of 36 MPa to 40 MPa, with the majority of the elements having a compressive strength of 36 MPa. This value shows that the quality of existing concrete is still in the category of good structural concrete so that it is able to fulfill its function as a load-bearing element.

The relatively uniform compressive strength value shows that the construction implementation process produces a fairly homogeneous quality of concrete. Although there is a difference in the compressive strength value between columns, the variation is still within a reasonable range and can be influenced by several factors, such as variations in the casting process, the level of concrete compaction, *the curing process*, the life of the concrete, and environmental conditions during the service life of the building.

However, the results of the Schmidt Rebound Hammer test only describe the hardness conditions of the concrete surface. The compressive strength value obtained is the result of estimation based on the rebound *number* so that it cannot be used to describe the internal condition of concrete as a whole. Therefore, testing using *the Ultrasonic Pulse Velocity* (UPV) method is needed as a complement in evaluating the quality of concrete.

Discussion of Ultrasonic Pulse Velocity (UPV) Results

The UPV test results showed that most of the column elements had concrete quality in the *Good* category, with a percentage of 97.22%, while only 2.78% were in the *Very Poor* category. These results show that in general concrete has a good degree of homogeneity so that ultrasonic waves can propagate at a relatively high speed.

The speed of ultrasonic wave propagation is affected by the density of concrete, material continuity, pore levels, and the presence of cracks or cavities in concrete. Concrete that has a solid internal structure will produce a higher propagation speed than concrete that has internal damage.

The existence of one column element that is included in *the Very Poor* category shows an indication of a decline in the internal quality of concrete at the location. This condition can be caused by voids, *microcracks*, concrete segregation, or imperfections in the casting process. Therefore, the results of the UPV test need to be interpreted together with the results of the visual inspection and *the Hammer Test* so that the actual condition of the structural elements can be evaluated more comprehensively.

Discussion of Structural Element Eligibility

The feasibility assessment of structural elements is carried out based on the integration of visual inspection results, *Hammer Test*, and UPV. This approach provides a more comprehensive picture than using only one test method.The results of visual inspection showed the presence of hairline *cracks* and local *honeycombing* on several column elements. Based on its characteristics, the damage is still local and has not shown any indication of a significant decrease in the capacity of the structure.

The findings are supported by the results of *the Hammer Test* which shows that the quality of existing concrete is in the range of 36-40 MPa, as well as the results of the UPV which indicate that almost all column elements have internal quality in the *Good category*. The combination of these results shows that the condition of existing concrete in general still meets the requirements as a structural element.

Thus, based on the results of the evaluation using *the Non-Destructive Test* (NDT) method, the structural elements of the column of the Tunas Building, Faculty of Engineering, Gunung Jati University are considered STILL FEASIBLE to carry out their structural functions. However, elements that show the results of UPV in the *Very Poor* category still require special attention and are recommended for further evaluation so that the cause of the deterioration in concrete quality can be identified more deeply.

Conclusion

Based on the results of visual inspection, Schmidt Rebound Hammer Testing, Ultrasonic Pulse Velocity (UPV) testing, and structural analysis using ETABS software, several conclusions were obtained as follows

The visual inspection results indicated that the existing condition of the structural elements was generally in good condition. The observed defects consisted of hairline cracks in several columns and localized honeycombing at column corners. Based on field observations, these defects were limited in area and did not indicate significant structural failure.

The results of the Schmidt Rebound Hammer Testing showed that the existing concrete quality met the requirements for structural concrete. The estimated compressive strength values obtained from the rebound hammer test were within the range used as the basis for structural modeling in ETABS. The results indicated that most columns maintained adequate surface strength with relatively uniform concrete homogeneity.

The Ultrasonic Pulse Velocity (UPV) testing results showed that most column elements had good concrete quality based on ultrasonic wave propagation velocity. However, several test points indicated medium-quality (questionable) concrete conditions that required further evaluation. Overall, the UPV results suggested that the internal integrity of the concrete remained adequate.

The correlation analysis between Schmidt Rebound Hammer Testing and UPV testing indicated a positive relationship, where higher rebound hammer values tended to correspond

with better concrete quality based on UPV measurements. These two methods provided complementary information in evaluating concrete conditions, with the rebound hammer test reflecting surface hardness and UPV testing providing insight into internal concrete integrity.

Structural modeling using ETABS, based on concrete quality obtained from field testing, was successfully performed using loading combinations in accordance with SNI 1726:2019 and SNI 2847:2019. The evaluation results showed that most structural elements satisfied the required design capacity criteria.

The ETABS Design Check results indicated that nearly all column and beam elements were in a safe condition. However, one column element on the second floor showed a failure status and required further evaluation. This condition indicated that the element capacity was insufficient to withstand the applied load demands based on the numerical analysis results.

Overall, based on visual inspection, NDT testing, and numerical analysis using ETABS, the Tunas Building of Gunung Jati University remained structurally serviceable. However, special attention should be given to the column element that did not meet the required capacity criteria to ensure long-term structural safety and reliability.

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