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Code-Based Superstructure Safety Evaluation and Serviceability Margin Assessment of the North Minahasa District Government Library Construction Project

Josef Arnoldus Johni Sumajouw^{1*}, Wellem Toad², Mario Marthen Luther Moningka³,
Novriana Amelia Pangemanan⁴, Merci Freki Hosang⁵

Politeknik Negeri Manado

Corresponding Author: Josef Arnoldus Johni Sumajouw josefsumajouw6@gmail.com

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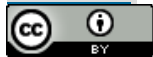
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ABSTRACT

This study evaluates the safety and serviceability performance of the superstructure of the North Minahasa District Government Library building using a code-based numerical analysis approach. The reviewer concern regarding research gap and novelty was addressed by shifting the paper from a simple reinforcement calculation report into an integrated assessment of load classification, ETABS modeling, drift control, and demand-capacity margin interpretation. Primary data consisted of site observation and verification of building information, while secondary data consisted of working drawings, material specifications, response spectrum parameters, and Indonesian structural design standards. The structure was modeled using ETABS, and the outputs were interpreted through inter-story drift checks, internal force demand, and reinforcement capacity verification for beams, columns, and slabs. The results show that the maximum X-direction drift utilization is 40.56% of the allowable limit and the maximum Y-direction drift utilization is 41.45% of the allowable limit. Beam B1 has flexural and shear demand-capacity ratios of 0.63 and 0.41, while Beam BK1 has ratios of 0.45 and 0.26. Column K1 has a shear demand-capacity ratio of 0.74, whereas Column K2 reaches 1.00 and is therefore identified as the governing member that requires strict detailing and construction quality control. The study concludes that the superstructure satisfies the evaluated code-based requirements, but further research should include nonlinear seismic analysis, material testing, as-built survey verification, and soil-structure interaction modeling

INTRODUCTION

Structural safety is a critical requirement in the design and construction of public buildings, including library facilities. A library building is not only an educational facility but also a public asset that may accommodate users, collections, equipment, and service activities at the same time. Therefore, its structural elements must be capable of resisting gravity loads and lateral loads while maintaining acceptable serviceability performance.

Columns, beams, and slabs are the primary superstructure elements that transfer loads from the upper floors to the supporting structural system. The performance of these elements is commonly evaluated through internal forces, reinforcement requirements, and deformation control. For buildings in seismic regions, recent studies emphasize that displacement and inter-story drift are essential indicators for assessing structural response and serviceability performance, not merely secondary outputs of structural software (Afiah et al., 2025).

In Indonesia, code-based structural assessment is strongly influenced by load classification, seismic response parameters, material strength, and detailing requirements. Comparative studies on reinforced concrete structures show that the selection of spectral response input may influence the calculated structural demand and may reveal critical behavior in selected components, especially shear-sensitive elements (Sakul et al., 2025). In addition, changes in concrete design standards affect calculation assumptions, required reinforcement area, and the interpretation of structural modeling outputs (Oktafiani et al., 2025).

Research gap and novelty. Previous project-based structural papers often stop at reporting reinforcement dimensions and stating that the structure is safe. Such reporting is useful but still limited because it does not clearly classify the input data, does not explain the analysis workflow, and

does not interpret the safety reserve of each structural element. The gap addressed in this paper is the lack of a structured case-based evaluation that connects project data classification, SNI-based load assignment, ETABS modeling, drift control, and demand-capacity margin interpretation for a public library building in North Minahasa.

The novelty of this study lies in its integrated serviceability-oriented assessment. Instead of only presenting reinforcement outputs, this paper identifies the governing structural response using drift utilization and demand-capacity ratios. The objective of this study is to evaluate whether the superstructure of the North Minahasa District Government Library building satisfies the applicable code-based strength and serviceability requirements and to identify structural elements that require special attention during construction quality control.

METHODS

Research Design

This study uses a quantitative case-study design. The quantitative aspect is reflected in load calculation, numerical structural modeling, internal force analysis, drift control, and reinforcement verification. The case-study aspect is reflected in the use of actual project data from the North Minahasa District Government Library construction project. The method is not intended to generalize all public buildings, but to produce a replicable technical workflow for evaluating similar reinforced concrete public buildings.

Data Classification and Sources

To improve methodological clarity, the data were reclassified into primary data, secondary project data, regulatory data, and analytical output data. This classification avoids the ambiguity found in the initial manuscript, where literature sources and project documents were not clearly separated.

Table 1. Data Classification and Function in the Structural Assessment

Data class	Data item	Source	Function in analysis	Validation/control
Primary data	Site observation and general building information	Field observation during project/internship period	Confirms building function, project condition, and observable structural information	Cross-check with project drawings
Secondary project data	Floor plans, sections, detail drawings, dimensions, material specifications	Project working drawings and technical documents	Defines model geometry, member dimensions, slab thickness, and material properties	Consistency check between drawings and model input
Regulatory data	SNI 1727:2020, SNI 1726:2019, SNI 2847:2019, SNI 8900:2020	Indonesian National Standards	Defines load categories, seismic criteria, concrete design requirements, and simplified RC design guidance	Code-based compliance check
Seismic input data	RSA PUPR 2021 response spectrum parameters for North Minahasa	PUPR response spectrum platform	Defines seismic demand parameters for ETABS modeling	Verification of location-based spectral parameters
Analytical output data	Story drift, internal forces, required/provided reinforcement, capacity margin	ETABS output and manual verification	Determines safety status and governing elements	Demand-capacity and allowable drift comparisons

Analytical Procedure

The analysis followed a staged workflow so that every output could be traced back to the input

data and code requirement. The workflow is summarized in Table 2.

Table 2. Analytical Workflow Used in the Revised Study

Stage	Main activity	Output	Reviewer-oriented improvement
1	Collect and classify drawings, material data, load references, and seismic parameters	Verified data set	Clearer data classification
2	Define material properties, member dimensions, slab thickness, and structural grid in ETABS	Three-dimensional structural model	Traceable model assumptions
3	Assign dead load, additional dead load, live load, and earthquake load according to SNI criteria	Load cases and load combinations	Better link between function and load category
4	Run structural analysis to obtain drift, displacement, moment, shear, and axial force	Structural response data	Outputs interpreted beyond raw numbers
5	Check inter-story drift against allowable drift and calculate utilization ratio	Serviceability margin	Directly answers safety/serviceability performance
6	Verify beam, column, and slab reinforcement capacity against demand	Demand-capacity ratio	Identifies governing structural members
7	Synthesize conclusions, limitations, and future research directions	Improved discussion and research scope	Addresses reviewer comments

Evaluation Criteria and Output Parameters

The evaluation criteria consisted of strength and serviceability checks. Strength was evaluated by comparing internal force demand with nominal member capacity, while serviceability was evaluated through inter-story drift. The key output parameters were ultimate moment (M_u), shear force (V_u), axial force (P_u), nominal flexural capacity (M_n), nominal shear capacity (V_n), required reinforcement area, provided reinforcement area, and drift utilization ratio. A demand-capacity ratio below or equal to 1.00 was considered acceptable, but values close to 1.00 were treated as governing conditions that require construction quality control attention.

RESULTS AND DISCUSSION

Load Classification

The additional dead load was calculated from architectural and finishing components. For floor slabs on Levels 2 and 3, the additional dead load consists of 1 cm sand layer, 1 cm mortar,

ceramic tile, ceiling, and ceiling suspension, resulting in 79 kg/m². For the DAK slab, the additional dead load consists of MEP, ceiling, and ceiling suspension, resulting in 43 kg/m². Wall loads applied to floor beams include lightweight brick walls of 230 kg/m and curtain wall loads of 240 kg/m. Wall load on DAK beams is 86.25 kg/m. The roof frame additional dead load consists of spandek galvanized roof, ceiling, ceiling hangers, and MEP, resulting in 45.8 kg/m².

Live loads were assigned based on the building function as a library. The live load for Levels 2 and 3 is 2.87 kN/m², while the live load for the DAK slab is 0.96 kN/m². These values were used to ensure that the structural model represents the functional use of the building and not only its geometric configuration.

The seismic input was based on the 2021 PUPR Response Spectrum Analysis for the North Minahasa District Government Library location. The

parameters used in the ETABS model are shown in Table 3 and Figure 1.

Table 3. Response Spectrum Parameters for the North Minahasa District Government Library

Parameter	Value	Unit
PGAm	0.4697	g
Ss	1.0405	g
S1	0.4684	g
TL	12	second
Sds	0.74	g
Sd1	0.71	g
Fa	2.0	-
Fv	2.8	-
T0	0.19	second
Ts	0.96	second

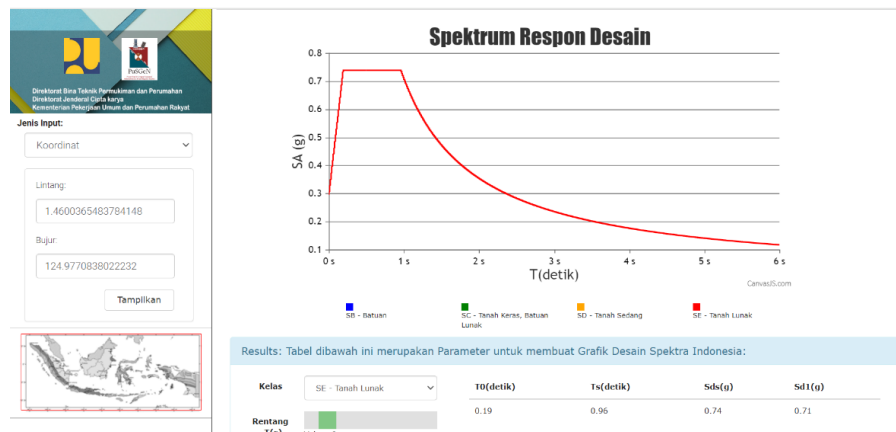


Figure 1. Response spectrum of the North Minahasa District Government Library Location

ETABS Structural Modeling

The structural model was developed using ETABS. The concrete strength was K250 or approximately 20 MPa. The reinforcement steel strengths used in the model and manual verification were BJTS = 400 MPa and BJTP = 240 MPa. The cross-sectional dimensions used in the model were: Column K1 = 400 mm × 500 mm, Column K2 = 400 mm × 400 mm, Beam B1 = 300 mm × 500 mm, Beam BK1 = 300 mm × 500 mm, Roof Beam RB = 200

mm × 500 mm, and slab thickness = 120 mm. After load input and model analysis, the outputs reviewed in this paper included inter-story drift, internal forces, and reinforcement adequacy.

Inter-Story Drift Control

Inter-story drift was evaluated in the X and Y directions to assess serviceability under lateral loading. The results show that all story drifts remain below the allowable limits. The detailed results are shown in Table 4 and Table 5.

Table 4. X-Direction Inter-Story Drift Criteria Check

Story	h (mm)	δ_{xe} (mm)	Δ (mm)	Δ_i (mm)	Δ_{allow} (mm)	Status
4	1500	17.077	93.92	0.78	30	OK
3	4400	16.935	93.14	29.12	88	OK
2	4400	11.641	64.03	35.69	88	OK
1	4400	5.152	28.336	28.34	88	OK

Table 5. Y-Direction Inter-Story Drift Criteria Check

Story	h (mm)	δ_{xe} (mm)	Δ (mm)	Δ_i (mm)	Δ_{allow} (mm)	Status
4	1500	14.976	82.37	1.33	30	OK
3	4400	14.734	81.04	13.51	88	OK
2	4400	12.278	67.53	36.48	88	OK
1	4400	5.645	31.0475	31.05	88	OK

The highest X-direction drift utilization occurs at Story 2 with 35.69 mm against an allowable value of 88 mm, equivalent to 40.56% utilization. The highest Y-direction drift utilization also occurs at Story 2 with 36.48 mm against 88 mm, equivalent to 41.45% utilization. This indicates that the lateral serviceability performance remains within the allowable drift criteria, with a reserve of approximately 58.55% in the governing Y-direction condition.

Internal Forces and Reinforcement Verification

The ETABS analysis produced the governing internal forces for each structural element. For columns, the maximum shear force is 81.9605 kN, axial force is 105 kN, ultimate moment in the x-direction is 79,847.12 kNm, and ultimate moment in the y-direction is 122,354.3 kNm. For beams, the maximum shear force is 83,788.22 N and the ultimate moment is 108,429,957.00 Nmm. For slabs, the ultimate moments are 8.995 kN-m in the x-direction and 7.551 kN-m in the y-direction. These values were used as the basis for reinforcement verification.

Table 6. Beam Reinforcement Verification Results

Beam type	Dimensions (mm)	Mu max (Nmm)	Vu max (N)	Tension reinforcement	Compression reinforcement	Mn (Nmm)	Vn (N)
B1	300×500	108,429,957	83,788.22	4D19	3D19	171,607,782.2	206,641.8
BK1	300×500	108,429,957	83,788.22	6D19	3D19	241,236,739.5	321,009

Table 7. Column Reinforcement Verification Results

Column type	Dimensions (mm)	Pu max (N)	Vu max (N)	Main reinforcement	Vn (N)
K1	400×500	150,000	81,960.5	14D19	110,249.3
K2	400×400	150,000	81,960.5	12D19	81,960.5

Table 8. Slab Reinforcement Verification Results

Plate type	Mux max (Nmm)	Muy max (Nmm)	Main reinforcement	As required (mm ²)	As provided (mm ²)
X-direction plate	8,995,000	7,551,000	Ø10-100	288.50	523.33
Y-direction plate	8,995,000	7,551,000	Ø10-100	272.00	523.33

Serviceability and Demand-Capacity Margin

Interpretation

A key addition in this revised manuscript is the interpretation of analysis outputs through utilization ratios. This allows the safety statement to be supported by a clear margin rather than by a general

statement that the structure is safe. The utilization ratio is calculated as demand divided by allowable limit or available capacity. Values below 1.00 indicate that the evaluated demand does not exceed the relevant limit, while values approaching 1.00 indicate members that require stronger construction quality control.

Table 9. Serviceability and Demand-Capacity Margin Interpretation. *For Slab Reinforcement, Ratio is Provided Area Divided by Required Area

Item evaluated	Demand / limit or capacity	Utilization ratio	Reserve margin	Interpretation
X drift, Story 2	35.69 / 88 mm	0.4056	59.44%	OK, governing X-direction drift
Y drift, Story 2	36.48 / 88 mm	0.4145	58.55%	OK, governing Y-direction drift
Beam B1 flexure	108.43 / 171.61 million Nmm	0.6318	36.82%	OK
Beam B1 shear	83.79 / 206.64 kN	0.4055	59.45%	OK
Beam BK1 flexure	108.43 / 241.24 million Nmm	0.4495	55.05%	OK
Beam BK1 shear	83.79 / 321.01 kN	0.2610	73.90%	OK
Column K1 shear	81.96 / 110.25 kN	0.7434	25.66%	OK
Column K2 shear	81.96 / 81.96 kN	1.0000	0.00%	Meets minimum capacity, governing member
Slab X reinforcement	523.33 / 288.50 mm ²	1.814*	81.40% excess area	OK, provided reinforcement

Item evaluated	Demand / limit or capacity	Utilization ratio	Reserve margin	Interpretation
				exceeds requirement
Slab Y reinforcement	523.33 / 272.00 mm ²	1.924*	92.40% excess area	OK, provided reinforcement exceeds requirement

CONCLUSION

- The superstructure of the North Minahasa District Government Library building satisfies the evaluated code-based strength and serviceability requirements under the modeling assumptions used in this study.
- The maximum X-direction drift utilization is 40.56% of the allowable limit, and the maximum Y-direction drift utilization is 41.45% of the allowable limit. These values indicate that the structure remains within the allowable drift criteria.
- Beam B1 and Beam BK1 show acceptable flexural and shear demand-capacity ratios. Beam B1 has the higher flexural utilization ratio of 0.63, while Beam BK1 has a lower flexural utilization ratio of 0.45.
- Column K1 has an acceptable shear utilization ratio of 0.74. Column K2 reaches a shear utilization ratio of 1.00, meaning it meets the minimum capacity requirement but has no additional shear reserve in the reported calculation. Column K2 is therefore identified as the governing member requiring strict construction quality control.
- The slab reinforcement is adequate because the provided reinforcement area exceeds the required area in both x and y directions.

Research Limitations

- The study is based on project drawings, available specifications, field observation, and numerical modeling. It does not include

destructive material testing or non-destructive in-situ concrete strength testing.

- The analysis uses code-based response spectrum assessment and does not include nonlinear pushover analysis or nonlinear time-history analysis.
- The study focuses on the superstructure. Soil-structure interaction, detailed foundation behavior, and construction-stage effects were not modeled in detail.
- The study assumes that construction quality follows the drawings and specifications. Deviations in reinforcement placement, concrete strength, or workmanship may alter actual structural performance.

Further Research Directions

- Future research should include nonlinear pushover analysis to evaluate plastic hinge formation and performance level under increasing lateral loads.
- Future studies can use nonlinear time-history analysis with selected ground motion records to obtain a more realistic seismic response for North Sulawesi seismic conditions.
- As-built survey, rebound hammer or ultrasonic pulse velocity testing, and reinforcement scanning should be added to verify the actual built condition.
- A complete structural reliability assessment can be developed by integrating superstructure response, foundation performance, soil-structure interaction, and construction quality audit data.

Further studies may integrate Building Information Modeling (BIM) with structural analysis to improve data traceability, quantity verification, and future maintenance planning for public

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