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Serviceability Margin and Foundation Reserve Assessment of a Reinforced Concrete Airport Terminal Structure in Bolaang Mongondow, Indonesia

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ABSTRACT

This paper presents a serviceability-centered reappraisal of a reinforced concrete airport terminal structure in Bolaang Mongondow, Indonesia. Unlike the earlier design-oriented report that mainly documented member reinforcement and general structural safety, this study focuses on the location and magnitude of performance margins after design. Secondary structural outputs from an ETABS v.21 model, response spectrum parameters, wind pressure results, bored-pile bearing capacity, and settlement estimates were reorganized into demand-capacity ratios. Inter-story drift, bored-pile bearing, and foundation settlement were selected as the primary observation variables because they directly indicate serviceability, reserve capacity, and potential operational risk for a public terminal building. The analysis shows that the upper story drift is the controlling serviceability indicator. The maximum drift demand in both X and Y directions reaches 29.04 mm against an allowable value of 30.00 mm, producing a demand-capacity ratio of 0.968 and leaving only 3.2% residual drift margin. In contrast, the bored-pile foundation still has a bearing-capacity demand ratio of 0.715, equivalent to a capacity reserve of about 39.8% relative to the applied maximum axial demand. The estimated pile settlement of 4.956 mm corresponds to only 19.5% of the 25.4 mm serviceability limit. These findings indicate that the foundation response is not the controlling issue; instead, construction tolerance, diaphragm action, cladding connection, and nonstructural components at the upper level deserve closer post-design verification. The proposed reserve-based reading provides a practical quality-control layer for airport terminal structures located in seismic regions

INTRODUCTION

Airport terminal buildings are public facilities with high occupancy, continuous operational demand, and strict serviceability expectations. In such facilities, structural safety is not only about whether a beam, column, slab, pile cap, or bored pile satisfies strength requirements. A building that satisfies strength checks can still create operational risk when lateral drift approaches the allowable limit, when cladding connections are sensitive to movement, or when differential settlement is underestimated during construction.

The available design documentation for the Bolaang Mongondow Airport terminal has already reported structural member design, reinforcement requirements, bored-pile capacity, pile-cap reinforcement, tie-beam reinforcement, and general safety status under ETABS analysis. That earlier work is important as a design report. However, its dominant question was: are the structural elements adequate and what reinforcement is required? This article asks a narrower but technically different question: which performance indicator controls the post-design reserve margin of the terminal structure?

This shift in question is not cosmetic. In performance-based structural thinking, deformation indicators such as inter-story drift are essential because they reflect the likely interaction between

global lateral response, nonstructural damage, second-order effects, and serviceability interruption. Recent seismic studies also show that drift-based indicators can describe structural vulnerability more directly than force-only checks, particularly for reinforced concrete frames and irregular structural systems (Çelebi & Kırtel, 2025; Sharma et al., 2025; Suliman & Lu, 2024).

The practical contribution of this paper is a reserve-based audit framework for an already-designed airport terminal. The framework converts the existing design results into demand-capacity ratios, ranks the controlling serviceability and foundation indicators, and provides post-design recommendations for verification before or during construction. Therefore, the study is positioned as a secondary analytical reappraisal, not as a duplicate redesign of the previously published article.

The previously published study on the same terminal building has already established member reinforcement and general structural safety. The gap addressed in this paper is the absence of a focused post-design serviceability reading. Specifically, the earlier report did not rank the closeness of drift, bearing capacity, and settlement demands to their respective limits. This paper fills that gap by using the same engineering context but a different analytical objective.

Table 1. Difference Between the Earlier Design Report and the Present Manuscript

Aspect	Earlier design-oriented paper	Present serviceability-oriented paper
Main question	Are the structural members safe and what reinforcement is required?	Which structural response has the smallest remaining reserve?
Main output	Reinforcement of columns, beams, slabs, bored piles, pile caps, and tie beams	Demand-capacity ratios for drift, bearing capacity, and settlement
Analytical emphasis	Strength design and member detailing	Post-design serviceability ranking and risk-based interpretation
Primary observation	General safety statement from ETABS and manual checks	Critical upper-story drift margin, foundation reserve, and construction-control implications

METHODS

Research Design

This study uses a quantitative secondary-analysis approach. The data are not treated as a new structural design dataset. Instead, previously available ETABS v.21 output, response spectrum parameters, wind calculations, foundation bearing capacity, and settlement values are reorganized into serviceability and reserve indicators. The method is suitable when an engineering design has been

completed but the reviewer needs a clearer picture of the controlling performance margin.

The methodological workflow is shown in Figure 1. The key step is the transformation of raw design outputs into comparable demand-capacity ratios. This allows drift, bearing capacity, and settlement to be evaluated on a common scale, where a value close to 1.00 indicates a response close to the acceptance limit.



Figure 1. Workflow of the Serviceability and Reserve-Based Reanalysis

Data Source and Scope Limitation

The building case is a reinforced concrete airport terminal structure in Bolaang Mongondow, North Sulawesi. The analyzed structural data include material strength, cross-section dimensions, response spectrum parameters, wind pressure calculation, inter-story drift output, internal forces, bored-pile axial demand, bored-pile bearing capacity, and settlement. The scope is limited to post-design evaluation; therefore, no new geotechnical

investigation, material testing, or nonlinear time-history analysis is claimed in this manuscript.

Because this is a secondary analysis, the validity of the findings depends on the accuracy of the original modeling assumptions, design load combinations, soil data, and ETABS model. The proposed contribution is the technical interpretation and ranking of margins, not the generation of new raw test data.

Table 2. Main Input Data Used for Reserve-Based Analysis

Category	Parameter	Value used in analysis
Material	Concrete compressive strength	$f_c = 25$ MPa
Material	Reinforcement strength	BJTS = 420 MPa; BJTP = 280 MPa
Geometry	Column section	800 mm x 800 mm
Geometry	Beam section	300 mm x 150 mm
Geometry	Floor slab thickness	120 mm, interpreted from design summary
Seismic	Response spectrum parameters	$S_s = 1.50$ g; $S_1 = 0.60$ g; $S_d = 0.80$ g; $S_{d1} = 0.80$ g
Wind	Basic wind speed and pressure	$V = 40$ m/s; $q_h = 1092.12$ N/m ²
Foundation	Maximum axial demand	$P_u = 121.0204$ tons
Foundation	Allowable bearing capacity	$Q_a = 169.2239$ tons
Foundation	Estimated settlement	$S = 4.956$ mm; allowable limit = 25.4 mm

Demand-Capacity Indicators

Three normalized indicators were used. A value below 1.00 indicates that demand remains within the selected limit. A value near 1.00 indicates a narrow reserve and should be checked carefully during detailing, construction, and inspection.

$$DCR_{drift} = \Delta / \Delta_{allowable}$$

$$DCR_{bearing} = P_u / Q_a$$

$$DCR_{settlement} = S / S_{allowable}$$

The remaining serviceability margin was calculated as 1 - DCR. For bearing capacity, an additional reserve ratio was calculated as Q_a / P_u . This ratio expresses how many times the available

allowable capacity exceeds the applied maximum axial demand.

RESULTS AND DISCUSSION
Inter-story drift utilization

The inter-story drift results show that the upper story is the controlling location. At the 10 m level, the drift demand is 29.04 mm in both X and Y directions, while the allowable drift is 30.00 mm. This produces a DCR of 0.968 and a remaining margin of only 3.2%. Lower levels have much larger reserves, indicating that the drift response is concentrated at the upper segment of the structure rather than uniformly distributed along the height.

Table 3. Inter-Story Drift Demand-Capacity Ratios

Direction	Level	Story height (mm)	Drift demand (mm)	Allowable drift (mm)	DCR	Margin
X	10 m	2000	29.04	30.00	0.968	3.2%
X	8 m	2000	11.34	30.00	0.378	62.2%
X	6 m	2000	6.04	30.00	0.201	79.9%
X	4 m	4000	2.38	60.00	0.040	96.0%
Y	10 m	2000	29.04	30.00	0.968	3.2%
Y	8 m	2000	11.34	30.00	0.378	62.2%
Y	6 m	2000	3.98	30.00	0.133	86.7%
Y	4 m	4000	4.44	60.00	0.074	92.6%

Figure 2 compares the critical drift index against the foundation indicators. The drift demand is closest to

the limit, while the settlement index is the least critical among the evaluated indicators.

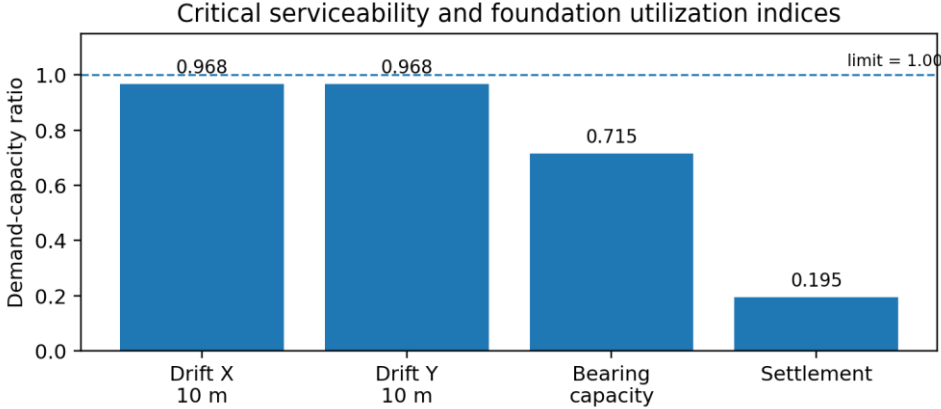


Figure 2. Utilization Ratios for Controlling Drift and Foundation Indicators

Wind pressure reading

The wind calculation gives a velocity pressure q_h of 1092.12 N/m². The calculated pressure on the windward side is 278.49 N/m², while suction on the leeward side is -185.66 N/m². The

windward pressure is about 1.50 times the absolute leeward suction value. These values are lower than the seismic drift concern in the present output set, but they remain important for facade, roof sheeting, anchor, and cladding connection checks.

Table 4. Wind Pressure Values Used for Serviceability Interpretation

Wind item	Formula basis	Value	Interpretation
Velocity pressure	$q_h = 0.613 K_z K_{zt} K_d V^2$	1092.12 N/m ²	Reference pressure
Windward pressure	$p = q_h G C_p$	278.49 N/m ²	Positive pressure on incoming side
Leeward suction	$p = q_h G C_p$	-185.66 N/m ²	Suction on outgoing side
Pressure asymmetry	$ \text{windward} / \text{leeward} $	1.50	Windward pressure governs facade pressure magnitude

Bored-Pile Capacity and Settlement Reserve

The bored-pile foundation has a maximum axial demand of 121.0204 tons and an allowable bearing capacity of 169.2239 tons. The resulting bearing utilization is 0.715, meaning the foundation demand uses about 71.5% of the available allowable capacity. Expressed as a capacity-to-demand ratio, the foundation has about 1.40 times the applied maximum axial demand.

The estimated settlement is 4.956 mm. When compared with the 25.4 mm settlement limit used in the design documentation, the settlement utilization ratio is 0.195. This means the settlement demand is only about 19.5% of the selected limit, leaving about 80.5% settlement reserve. From a reserve-based perspective, settlement is not the controlling serviceability item in the current dataset.

Table 5. Foundation Reserve Indicators

Indicator	Demand	Limit or capacity	Ratio	Engineering meaning
Bearing capacity	$P_u = 121.0204$ tons	$Q_a = 169.2239$ tons	0.715	Safe, 39.8% reserve relative to demand
Capacity-to-demand	Q_a / P_u	-	1.398	Allowable capacity is about 1.40 times demand
Settlement	$S = 4.956$ mm	$S_{allow} = 25.4$ mm	0.195	Large serviceability reserve

Ranking of controlling performance indicators

The results were ranked according to DCR magnitude. The highest DCR is the upper-story drift response in both main directions. Bearing capacity is the second controlling indicator, but it still has a moderate reserve. Settlement is the least critical of

the analyzed indicators. This ranking matter because it changes the practical post-design priority: the reviewer should not only repeat reinforcement checks, but should prioritize lateral serviceability verification and nonstructural component compatibility at the upper level.

Table 6. Performance Ranking Based on Demand-Capacity Ratio

Rank	Indicator	Critical value	DCR	Post-design priority
1	Inter-story drift at 10 m, X and Y	29.04 mm / 30.00 mm	0.968	Verify diaphragm behavior, drift compatibility, facade joints, and construction tolerance
2	Bored-pile bearing capacity	121.0204 tons / 169.2239 tons	0.715	Confirm soil data, pile length, workmanship, and field quality control
3	Bored-pile settlement	4.956 mm / 25.4 mm	0.195	Monitor as serviceability item, but not controlling in current output

Why the drift margin matters

The most important finding is the narrow residual drift margin at the upper story. A DCR of 0.968 does not mean failure, because the demand still remains below the allowable drift. However, it means that the acceptance boundary is close. Small changes in stiffness modeling, cracked-section assumptions, diaphragm representation, mass distribution, nonstructural load, or construction tolerances may move the result closer to the limit.

For an airport terminal, this issue is practical. Drift can affect glass panels, ceiling systems, MEP supports, partitions, roof cladding, and movement joints. These components may experience serviceability disruption even when the primary structural elements are safe. Therefore, the upper story should be treated as a verification zone during shop-drawing review, construction supervision, and final structural inspection.

Why the foundation is not the controlling issue

The bored-pile foundation is safer in relative terms than the upper-story drift response. The axial demand uses 71.5% of the available allowable bearing capacity, while settlement uses only 19.5% of the selected settlement limit. This does not remove the need for pile quality control; it only means that the calculated foundation margin is wider than the drift margin.

The finding also suggests that additional field verification should be targeted. If resources are limited, the design reviewer should maintain standard pile integrity and construction checks while giving extra attention to structural lateral stiffness, nonstructural compatibility, and upper-level drift-sensitive details.

Technical recommendations for post-design review

- Recheck the ETABS model using cracked-section stiffness assumptions and confirm whether the upper-story drift remains below the allowable limit.
- Verify diaphragm action and load transfer from slab, beams, and roof framing, especially at the level where the drift ratio is highest.
- Review glass, facade, ceiling, and MEP support details for drift compatibility, because these components often govern operational serviceability in terminal buildings.
- Confirm soil parameters and pile workmanship through project quality-control records, even though bearing and settlement ratios show adequate reserve.
- Provide a post-construction monitoring note for settlement and visible nonstructural cracking during early operation.

CONCLUSION

1. This paper develops a new serviceability and reserve-based interpretation of the Bolaang Mongondow Airport terminal structure using previously available design outputs. The technical focus is different from the earlier reinforcement-design article because the present manuscript ranks structural response margins rather than repeating member detailing.
2. The controlling indicator is the upper-story drift at the 10 m level. The drift demand of 29.04 mm against a 30.00 mm limit produces a DCR of 0.968 in both X and Y directions, leaving only 3.2% residual margin.
3. The bored-pile foundation is not the controlling performance item. The bearing DCR is 0.715, while the settlement DCR is 0.195. These results indicate adequate foundation reserve under the available data.
4. The post-design priority should be upper-level lateral serviceability, nonstructural drift compatibility, diaphragm verification, and construction tolerance control. This is especially

relevant for airport terminal buildings where operational continuity depends on both structural and nonstructural performance.

5. The study should be treated as a secondary analysis. Any future journal submission must transparently cite the previously published design article and explain that the present paper uses a different research question and analytical output.

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