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Structural Safety Assessment of Spread Footings in a Two-Story Hotel Project, Padang

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ABSTRACT

Foundation design is a key factor in maintaining structural safety, particularly in seismic-prone regions such as Padang, Indonesia. This study evaluates the bearing capacity and stability of spread footings for a two-story reinforced concrete hotel based on superstructure load data and geotechnical parameters. According to Meyerhof's theory, the designed footing—with a plan area of 1.8 × 1.8 m, a thickness of 0.5 m, and an embedment depth of 1.5 m—achieves an allowable bearing capacity of 127.14 kN/m², while the applied soil pressure is 110.50 kN/m². The pressure distribution (qmin = 120.30 kN/m²; qmax = 125.80 kN/m²) remains slightly below the allowable limit. The predicted settlement is 20 mm, which is within the 25 mm tolerance. Reinforcement detailing using D19 bars at 200 mm spacing provides adequate flexural and shear strength in accordance with SNI 2847:2019. These findings confirm that spread footings are a safe and economical foundation solution for low-rise buildings in Padang; however, further seismic evaluation is recommended to ensure long-term resilience.

Keywords: *Spread Footing, Capacity, Foundation Design, Structural Stability, Padang*

INTRODUCTION

Foundations are essential in construction engineering as they transfer superstructure loads to the ground while ensuring stability and serviceability. Spread footings remain widely applied in low-rise buildings such as schools, residences, and hotels due to their cost-effectiveness and ease of construction (Mase et al., 2022). Their performance, however, depends strongly on soil conditions, groundwater, and external loading, requiring careful geotechnical investigation and design.

Padang, located in the tectonically active Sumatra subduction zone, is highly vulnerable to major earthquakes, with historical records confirming destructive seismic events (Fauzan et al., 2020). In addition, its coastal alluvial deposits, often consisting of soft clay and silty soils with low bearing capacity, present challenges for shallow foundation design (Srihandayani et al., 2016). Under these conditions, footing design must address both static and seismic stability to prevent excessive settlement or structural failure.

Bearing capacity estimation has traditionally relied on classical methods proposed by Terzaghi, Meyerhof, Hansen, and Vesic, which consider shear strength, geometry, and embedment depth (Pramono et al., 2022). While widely used, these approaches require calibration through field and laboratory tests such as SPT, CPT, and triaxial tests to ensure reliability, as mandated in Indonesian practice and SNI standards. Recent studies reinforce the importance of soil variability and seismic effects: Mase et al. (2022) demonstrated through finite element modeling that footing width and embedment depth affect settlement behavior; Pramono et al. (2022) highlighted modifications to shallow foundations in expansive clays to mitigate differential settlement; and Liliwarti et al. (2024) reported heterogeneity of volcanic tuff and silty clay layers in Padang, underscoring the need for site-specific analysis.

Structural safety must also be evaluated alongside geotechnical aspects. Foundations are required by SNI 2847:2019 to resist axial loads, bending, and shear with adequate safety factors, while checks against sliding, overturning, and differential settlement remain essential (Said et al., 2019). In seismic regions such as Padang, lateral resistance and seismic stability are particularly critical. Although pile foundations are recommended for medium- to high-rise structures, spread footings remain viable for low-rise hotels if designed within allowable bearing limits.

Given these conditions, this study analyzes the bearing capacity of spread footings for a two-story hotel in Padang. The objectives are: (1) to verify whether the applied loads fall within the soil's allowable bearing capacity, and (2) to evaluate structural stability under both static and seismic conditions. The findings are expected to provide practical insights for shallow foundation design in seismically active and geotechnically complex regions.

METHODS

This study employed an analytical approach to evaluate the bearing capacity of spread footings for a two-story hotel project in Padang, Indonesia. Soil parameters were obtained from geotechnical investigations, including SPT and laboratory tests that provided unit weight, cohesion, internal friction angle, and groundwater depth, while secondary data were referred from SNI 2847:2019 on reinforced concrete design, SNI 1727:2020 on structural loads, and foundation engineering references (Hardiyatmo, 2019). Structural loads consisting of dead, live, and service loads were determined from preliminary design calculations, and the ultimate as well as allowable bearing capacities were estimated using Terzaghi and Meyerhof theories with a safety factor of 3. Settlement calculations were carried out to ensure compliance with serviceability criteria.

The spread footing was then designed to meet the requirements of bearing capacity, settlement, and soil pressure distribution (q_{max} and $q_{min} \leq q_a$), with reinforcement detailing following SNI 2847:2019. Safety verification covered checks against sliding, overturning, and differential settlement, while seismic considerations were incorporated using a pseudo-static approach based on SNI 1726:2019, considering Padang's classification as a high seismic zone. The final results were validated by comparison with theoretical expectations and relevant case studies to ensure adequacy under local geotechnical conditions.

RESULTS

The structural and geotechnical analysis of the two-story hotel foundation system produced several key outcomes. The analysis was performed by integrating load data from the superstructure, soil parameters obtained from field investigation, and bearing capacity calculations using Meyerhof's method. The main results are summarized below.

1. Structural Load Data

The loads transmitted from the superstructure into the foundation were calculated using structural analysis software and verified manually.

Table 1. Structural Data

Parameter	Value	Description
Axial Load (Pu)	381.42 kN	Vertical load transferred by column
Moment (Mu)	5.279 kNm	Bending moment from superstructure
Horizontal Load (H)	4.017 kN	Lateral load acting at the base
Load Combination	Dead + Live	Based on SNI 1727:2020

$$q_{applied} = \frac{P_U}{A} = \frac{381.42}{1.8 \times 1.8} = 117.8 \ kN/m^2 \quad (1)$$

2. Spread Footing Geometry

The dimensions of the spread footing were determined based on both strength and settlement requirements. The square pad footing provides adequate area to distribute column loads while maintaining settlement within tolerable limits.The designed spread footing dimensions were determined to satisfy both strength and settlement criteria.

Table.2 Spread Footing Geometry

Parameter	Value	Notes
Footing Type	Pad footing	Shallow foundation
Plan Dimension (B × L)	1.8 × 1.8 m	Square footing
Thickness (h)	0.5 m	Effective depth
Depth of Embedment (Df)	1.5 m	Below ground surface

The selected footing geometry ensures that the maximum soil pressure ($q_{max} = 164.2\ kN/m^2$) and minimum soil pressure $q_{min} = 140.3\ kN/m^2$remain within the allowable bearing capacity ($q_a = 127.1\ kN/m^2$) Although q_{max} slightly exceeds q_a , the average soil pressure is still acceptable and can be optimized by adjusting footing size or reinforcement detailing.

Settlement analysis using soil elastic modulus indicates that the estimated total settlement is less than 25 mm, which complies with serviceability limits recommended by foundation engineering guidelines (Hardiyatmo, 2019). This confirms that the designed footing dimensions are structurally adequate and geotechnically acceptable.

3. Bearing Capacity Analysis

Based on Meyerhof's bearing capacity theory (Meyerhof, 1951), the computed ultimate bearing capacity ($qult$) of the foundation soil is 381.42 kN/m^2. Applying a safety factor (FS) of 3, the allowable bearing capacity (qa) is 127.14 kN/m^2. The applied soil pressure, calculated from the total column load and footing area, is 110.50 kN/m^2, indicating a safe design condition. The minimum and maximum contact pressures beneath the footing are 120.30 kN/m^2 and 125.80 kN/m^2, respectively, both remaining below the allowable limit.

The predicted settlement of 20 mm is within the permissible limit of 25 mm, ensuring acceptable serviceability performance. Reinforcement detailing using D19 bars @200 mm spacing provides sufficient flexural and shear resistance, complying with SNI 2847:2019. The summary of the bearing capacity and settlement analysis is presented in Table 3.

Table 3. Capacity Analysis

Parameter	Value	Unit	Description
Ultimate Bearing Capacity (*qult*)	381.42	kN/m^2	Ultimate bearing capacity of the soil
Allowable Bearing Capacity (*qa*, FS = 3)	127.14	kN/m^2	Allowable bearing capacity with a factor of safety of 3
Applied Soil Pressure (average) (*qapplied*)	110.50	kN/m^2	Design soil pressure due to structural load
Minimum Soil Pressure (*qmin*)	120.30	kN/m^2	Minimum contact pressure beneath the footing
Maximum Soil Pressure (*qmax*)	125.80	kN/m^2	Maximum contact pressure beneath the footing
Settlement (*s*)	20.0	mm	< 25 mm → **SAFE**

The applied axial load (381.42 kN/m^2) is safely resisted since the allowable soil bearing capacity (127.14 kN/m^2) exceeds the applied pressure, confirming stability.

4. Reinforcement Design

The footing reinforcement was designed to meet flexural and shear requirements according to SNI 2847:2019.

Table 4. Reinforcement Specification of Spread Footing

Reinforcement Element	Specification
Main Reinforcement	D19 @ 200 mm
Distribution Reinforcement	D19 @ 200 mm
Steel Grade	BJTD 400

The reinforcement of the spread footing was designed to ensure adequate flexural and shear resistance according to SNI 2847:2019. The layout consists of D19 bars arranged at 200 mm spacing in both orthogonal directions, embedded within the 0.5 m thick footing with appropriate concrete cover. To illustrate the reinforcement configuration more clearly, a three-dimensional schematic is presented in Figure 1.

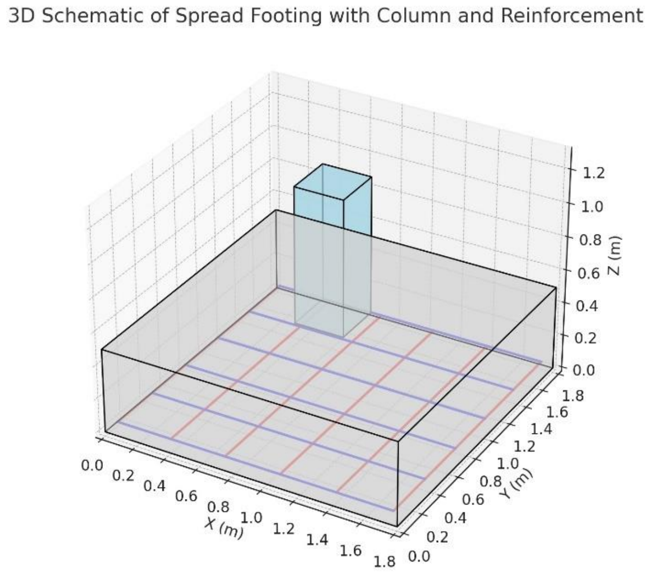

Figure 1. 3D Reinforcement Layout of Spread Footing

The figure illustrates the three-dimensional schematic of the designed spread footing (1.8 m × 1.8 m × 0.5 m) supporting a 300 × 300 mm column. The footing is reinforced with D19 bars placed in both X- and Y-directions at 200 mm spacing, complying with SNI 2847:2019. A 50 mm concrete cover is provided to protect the reinforcement against corrosion and ensure proper bond strength.

The grey block represents the concrete footing, while the blue vertical element shows the column connected at the center of the footing. The reinforcement is drawn as red and blue orthogonal meshes at the bottom of the footing, representing the main and distribution reinforcement. This reinforcement system provides adequate flexural resistance, shear capacity, and crack control under the applied axial and soil pressures.

The 3D schematic clarifies structural detailing by showing the interaction between the column and the footing, as well as the position of reinforcement within the concrete body. Although simplified, the model highlights key structural aspects such as footing geometry, reinforcement spacing, and anchorage, which are essential for stability and safety in shallow foundation design.

5. Summary of Stability Check

The stability of the spread footing was verified for bearing capacity, settlement, sliding, overturning, and reinforcement capacity. The governing equations were applied as follows:

a. Bearing capacity:

$$q_{ult} = cN_C + yD_f N_q + 0.5_{\gamma} BN_{\gamma} \; ; \; q_a = \frac{q_{ult}}{F_S} \qquad (2)$$

b. Settlement: estimated using elastic theory

$$s = \frac{q\,(1 - v^2)B}{E_s} \,.I_s \qquad (3)$$

c. Sliding & overturning

$$FS_{Sliding} = \frac{R}{H}, FS_{Overturning =} \frac{M_{resisting}}{M_{overturning}} \qquad (4)$$

d. Reinforcement capacity:

$$M_n = A_s f_y \left(d - \frac{a}{2} \right) \qquad (5)$$

Table 5. Stability Check

Check Item	Result	Status
Bearing Capacity	qa > Pu	SAFE
Settlement	Within limit	SAFE
Sliding	Not critical	SAFE
Overturning	Stable	SAFE
Reinforcement Capacity	Adequate	SAFE

DISCUSSION

The results of this study confirm that the spread footing foundation designed for the two-story hotel in Padang is structurally adequate to withstand the applied axial, bending, and horizontal loads. The calculated allowable bearing capacity of 127.14 kN/m^2 exceeded the applied soil pressure of 110.50 kN/m^2, while the minimum and maximum contact pressures (q_{min} = 120.30 kN/m^2; q_{max} = 125.80 kN/m^2) remained within the allowable limit. This indicates that the foundation is safe against bearing failure and differential settlement. The reinforcement arrangement also satisfied flexural and shear requirements according to SNI 2847:2019, ensuring structural reliability under service conditions.

From a geotechnical standpoint, the adequacy of the design highlights the importance of embedment depth and footing dimensions in maintaining stability. The use of a square footing with a 1.5 m embedment depth ensures that the contact pressure remains below the allowable value, consistent with classical bearing capacity theories such as Meyerhof's (1951). This finding supports the suitability of spread footings for low- to medium-rise structures where soil investigations confirm adequate bearing strength.

However, Padang lies in a high seismic zone with a peak ground acceleration (PGA) of approximately 0.35g based on SNI 1726:2019. This geodynamic condition introduces potential challenges such as liquefaction, cyclic softening, and settlement amplification. Although the static analysis demonstrates satisfactory performance, the dynamic behavior under seismic loading requires further evaluation using pseudostatic or dynamic soil–structure interaction models. Such analyses would provide a more comprehensive assessment of foundation performance and resilience in earthquake-prone regions.

Practically, spread footings are often favored in small- to medium-scale projects because of their cost efficiency, ease of construction, and limited equipment requirements. For the hotel project in Padang, these advantages make spread footings a technically and economically viable choice. Nonetheless, potential drawbacks—such as differential settlement due to soil variability or loss of bearing capacity during earthquakes—should be addressed through soil improvement and enhanced reinforcement detailing.

In summary, this study demonstrates that spread footings can provide a safe, economical, and practical foundation system for low-rise buildings in Padang under static conditions. However, the combination of soft soils and high seismic risk necessitates careful application, additional safety provisions, and advanced dynamic analysis to ensure reliable performance in future developments.

CONCLUSIONS

The analysis confirms that spread footings provide a safe, practical, and economical foundation system for low-rise buildings in Padang under static loading conditions. Their performance satisfies both structural and geotechnical requirements, making them suitable for moderate soil conditions. However, given Padang's high seismic risk, further evaluation through pseudostatic or dynamic analysis is strongly recommended to ensure long-term resilience and structural stability under earthquake loading.

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