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A Practically Method to Modify Shallow Foundation for Supporting Multy-Storeyed Building with CPT Data Tests

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ABSTRACT

A foundation aims to distribute upper structure loads as dead, live, and earthquake loads. A construction of medical building four stories called Mother and Children of RSUD Chasan Boisoirie as official hospital in Ternate city. Design of sub-structure results of the consulting were worked with shallow foundation with width B is the length (L) of 2,0 meters and depth (D_f) of 3,6m in field. However, condition was conducted by reinforcing and casting concrete for the foundation. There are some problems, i.e., ratio of foundation depth to the width B (λ) of 1,8 > 1,0. That can be collapsed of footing of foundation structure due to such shear punch due to an earthquake. Therefore, this research is followed National such as standard SNI, loading due to earthquake, learning CPT secondary data, checking soil layer data in the field, determining shear stress of foundation modification, checking soil stress beneath the foundation footing and calculation of the ground's flexural bar. Finally, the simulation results are given load as moment-x (M_x) of 23,97 tons, moment-y (M_y) of 23,86 tons and vertical load (P_{uv}) of 201,7 ton. Determining results of shear strength (ϕV_{np}) of 3.097,6 kN > 2017 kN (safe). Calculation is given a maximum stress of soil layer beneath foundation checked by σ_{max} of 863 kN/m² < q_{an} of 1.677,6 kN/m². Flexible bars for footing foundation due to vertical load and response of the subsoil layer were saved in controlled criteria.

Keywords: Bearing capacity, Earthquake load, Shallow foundation, CPT data

ABSTRAK

Pondasi bertujuan untuk mendistribusikan beban struktur atas seperti beban mati, beban hidup, dan beban akibat gempa. Pembangunan gedung medis empat lantai yang disebut *Mother and Children* of RSUD Chasan Boisoirie sebagai Rumah Sakit resmi di Kota Ternate. Desain sub-struktur hasil konsultasi menggunakan fondasi dangkal dengan lebar (B) sepanjang 2,0 meter dan kedalaman (D_f) 3,6 meter di lapangan. Namun, pelaksanaan fondasi dilakukan dengan penguatan dan pengecoran beton. Terdapat beberapa permasalahan, yaitu rasio kedalaman fondasi terhadap lebar B (λ) sebesar 1,8 > 1,0. Rasio ini dapat menyebabkan kolaps pada kaki fondasi akibat gesekan (shear punch) yang disebabkan oleh gempa. Oleh karena itu, penelitian ini mengikuti standar nasional seperti SNI, memeriksa beban akibat gempa, mempelajari data sekunder CPT, memeriksa data lapisan tanah di lapangan, menentukan tegangan geser pada modifikasi fondasi, memeriksa tegangan tanah di bawah kaki fondasi, dan menghitung batang lentur tanah. Hasil simulasi menunjukkan beban yang diberikan berupa momen-x (M_x) sebesar 23,97 ton, momen-y (M_y) sebesar 23,86 ton, dan beban vertikal (P_{uv}) sebesar 201,7 ton. Hasil perhitungan tegangan geser (ϕV_{np}) sebesar 3.097,6 kN, lebih besar dari 2.017 kN (aman). Perhitungan menunjukkan tegangan maksimum pada lapisan tanah di bawah fondasi yang dihitung sebesar σmax sebesar 863 kN/m², lebih kecil dari qan sebesar 1.677,6 kN/m². Batang lentur pada fondasi kaki yang diakibatkan oleh beban vertikal dan respons lapisan subsoil telah memenuhi kriteria pengendalian yang ditentukan.

Dengan demikian, desain fondasi tersebut dinyatakan aman dan stabil terhadap kondisi beban yang diberikan, termasuk efek gempa.

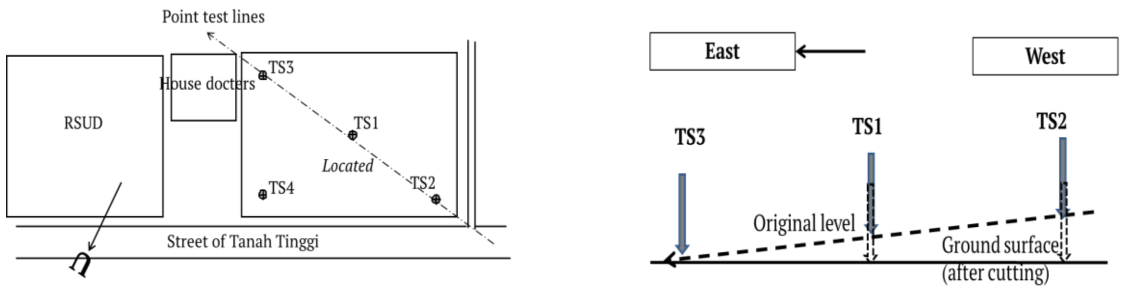
Kata kunci: Daya dukung, Pondasi modified, Beban gempa, Pondasi dangkal, data CPT

INTRODUCTION

In general, building construction design can be divided into 2 (two) parts: 1) the upper building structure, and 2) the lower building structure (Gauch *et al.*, 2023; Vuran *et al.*, 2025). Meanwhile, underfloor building structures usually use 2 (two) types of foundations: Shallow foundation and deep foundation. In which, a deep foundation can be designed with the type of well foundation, drill pile and pile (Qiu *et al.*, 2023). The field topography of the building construction area has a decreasing surface slope contour ranging from 8% to 20% west to east over a land elevation of more than 50 meters above the water sea level.

The foundation bearing capacity is considered the value of the mechanical parameters of the structure of the soil and rock layers (Zhang *et al.*, 2024). Field soil testing used to design the structure of the building under the construction of Mother and Children in the RSUD Chasan Boesoirie, which is located at Tanah Tinggi Ternate sub-district of Ternate city is using the Cone Penetration Test (CPT) data, it is referred SNI in 2008.

Figure 1 show that field soil investigation data using the CPT method for 4 (four) points of TS1 to TS4 have provided a cone tip resistance (q_c) of 250 kg/cm². Figure 1a showthat the placement of the CPT test, where a diagonal line project was carried out to map the results of qc values and land contours according to the field topography. While Figure 1b show the results of field data pieces by using the CPT method (Eslami & Gholami, 2005; Mayne & Illingworth, 2010; Suyuti, 2010; Suyuti & Arbain, 2017; Suyuti *et al.*, 2020; Mayne, 2021; Aouadja & Bouafia, 2022).



(a) (b)

Figure 1. Results of soil investigated by using CPT tests; (a) Layout placed points of CPT test, (b) Long section of CPT test

A problem of the substructure's design data using a shallow foundation with a square footing type, it is a cross-section of width B of 2.0 m, length L of 2.0 m and depth D_f of 3.6 m. A current shallow foundation planning criteria ratio is $\lambda = D_f/B$ of 1.8. The ratio λ should be $\lambda \leq 1.0$, so the foundation should be designed with a deep foundation type. Meanwhile, when the research study was carried out at that time, the work on assembling the pedestal iron and shallow foundation foot plate had been carried out by the implementing contractor and was ready for installation and casting.

Because of that, there needs to be a solution on how to improve the results of the foundation design for the contractor so that they can still use the pieces of iron that have been completed. Furthermore, the function of the substructure can transmit loads (moment, shear and vertical) from the superstructure (Deng *et al.*, 2023; Li *et al.*, 2024). So, this study aim is to find out a solution for modifying shallow foundation structures in reducing the potential for shear failure of the footplate foundation due to static and dynamic loads due to earthquake as shown in Figure 2.

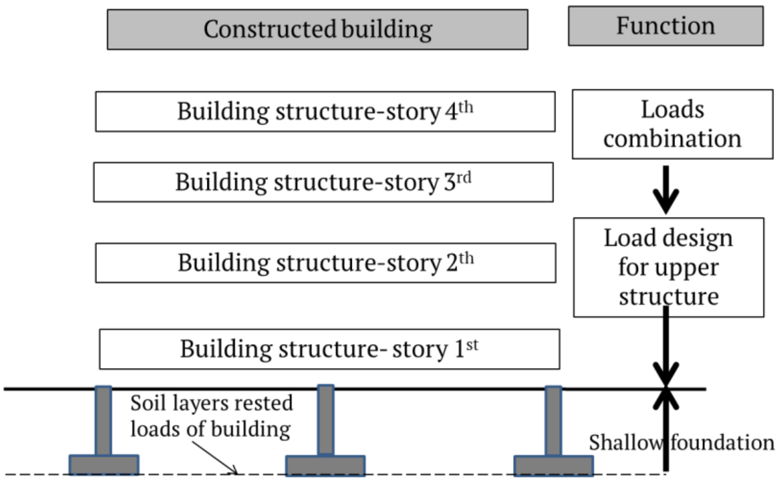


Figure 2. Illustration of procedure for designing construction with building functions

METHODOLOGY

This research uses a case study method which is complemented by comparing measurement results with standards and modeling them using computer software. To carry out scientific research, the method that the authors are used to make planning data on the superstructure loads of the hospital building, which is carried out in the following steps:

1. Following regulations such as Procedures for earthquake resistance (SNI, 2012), Requirements for structural concrete for buildings (SNI, 2013) concrete reinforcing steel (SNI, 2014), and the minimum load for planning buildings and other structures (SNI, 2013).
2. Input building planning data such as: The building consists of 4 (four) floors, located in Tanah Tinggi Sub-district, Ternate city, the building functions as a hospital, reinforced concrete building structure, floor height 4.0 m, concrete compressive strength (f'_c) of 20 MPa, yield stress of steel (f_y)of 400 MPa, elastic modulus of concrete (E_c) of 21,01 MPa, and superstructure calculation using FEM auxiliary program.
3. Determination of dimensions for beams, columns and floor slabs
4. Dead loads such as floor slab loads, roof slab loads, column dead loads, and live loads that work for hospital facilities.
5. Dynamic earthquake load spectrum response, such as determining the risk of building structures and earthquake priority factors, as shown in Table 1.

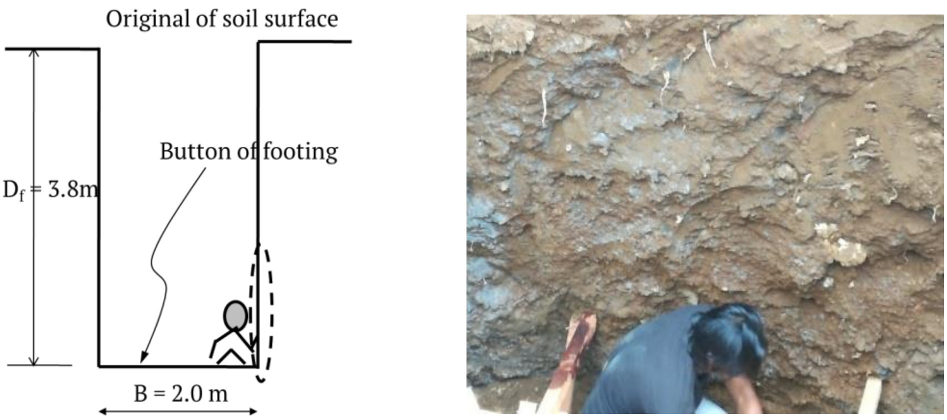
Table 1. Category risk and earthquake load factors

Function	Risk category	Earthquake factor
Hospital	IV	1,5

This study focused on the design of the substructure using: Data from the CPT test results (see Figure 1b). The resistance of the conical ends TS-2, TS-1 and TS-3 are given end resistance of conus (q_c) of 250 kg/cm², respectively at depth (D_f) of 2.0 m, 4.2 m and 4.6 m. In contractual, the results of shallow foundation planning were designed by using square pattern of footings with a cross-section of width (W) of 2.0 m, length (L) of 2.0 m and depth (D_f) of 3.60 m.

RESULTS AND DISCUSSION

The results section should include the findings of the study. The findings include data presented in tables, charts, graphs, and other figures (maybe placed among research text or on a separate page). A contextual analysis of this data explaining its meaning in sentence form. The results section should simply state the findings, without bias or interpretation, and arranged in a logical sequence. Typically most of the sentences in the results section will be in the past tense, some will be in the present tense, and very few, if any, will be in the future tense. The results of the CPT test for 4 (four) points are need to be checked for real conditions when excavation was completed in the field as shown in Figure 3 (Suyuti & Arbain, 2017).



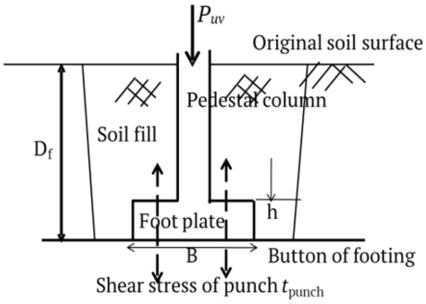
(a) (b)

Figure 3. Observed soil characteristics at the level button of foundation: (a) Illustrating shallow foundation, (b) Documentation of soil sampling

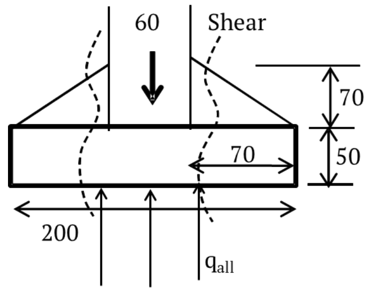
Figure 3 shows the following several parameters of design data for foundation in the field: a) width of foundation of 2.0 m, and length of 2.0 m, it is placed depth at 3.6 m, b) direct partial observation of the results of foundation excavations in the field is that the dominant soil layer is clay to a depth of approximately 2.0 m, while granular soil is in the form of sand to clay gravel at a depth of 3.6m, and c) the groundwater level is not found.

The results of the calculation of the water content and the volume weight of the subgrade soil layers are obtained sequentially water content (w) of 48% and soil bulk density (γ_s) of 1.9 kN/m^3. The selection of the foundation should take into account the following: a) functions of the upper structure of the building, b) the load volume and weight of the building superstructure, c) report data on the results of land investigations at the building site, d) earthquake loads of upper structures, and d) the cost to be involved.

The calculation of foundation stability is in the following sequence: a) use forces acting on the maximum foundation due to the earthquake load are obtained: Moment perpendicular and parallel to the image (M_x) of 23.97 kNm, and M_y of 23.86 kNm, with vertical load (P_{uv}) of 201.7 tons as shown in Figure 4, b) calculate shear stress of punch (t_{punch}) acting on the foundation structure, c) Determine allowable bearing capacity of foundation q_{all} , d) ultimate bearing capacity (q_{u2}) is obtained 375.3 ton/m^2, e) modification of the sole of the foundation with enlargement of the tip in equation, in calculation, it is found (q_{an}) of (450,4 – 30,96 to 2,5 = 168 ton/m^2, then check feasibility of vertical load vertical load pressure acting on the soil under the footing (σ_v) of 201.7 tons/ 1.44 m^2 of 140 tons/m^2 < q_{an} of 168 tons/m^2 (fulfillment), f) check foundation shear strength, and g) calculate soil stress under the foundation. The results of calculating and checking the soil stress acting on the base of the foundation are listed in Table 2.



(a)



(b)

Figure 4. A practical design of foundation in this study:
(a) Designed in the contractual, (b) Modified footing structure

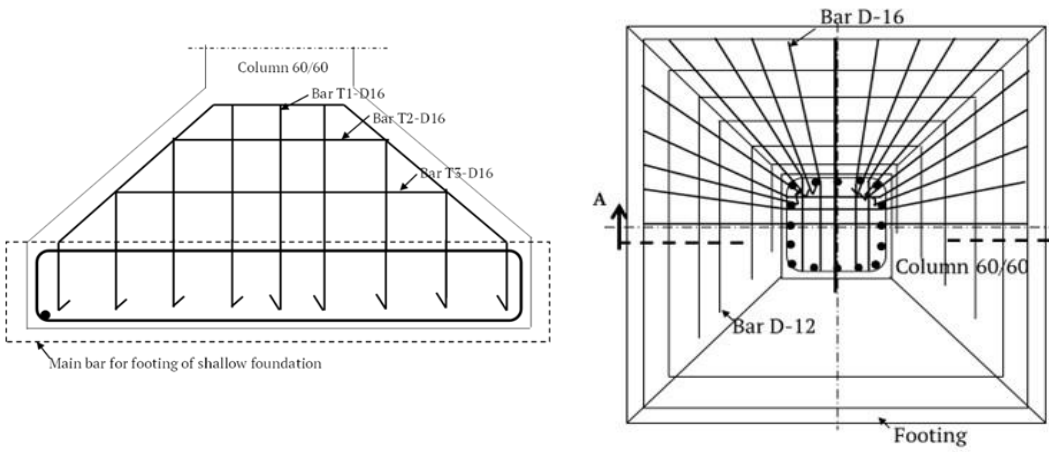
Table 2. Calculation results for before and after modified shallow foundation

Description	Equation	Before	After	Unit
Column shear force with load factor	P_{uv} =	2,017	2,017	kN
Quality of concrete K-300	f'_c= (0.83/9.81).300 =	25.38	25.38	MPa
Column point factor (center)	α_s =	40	40	
Width of column at direction of x and y	$b_x = b_y$ =	0.6	0.60	m
Distance center bars against side of concrete	d' =	0.0905	0.0905	m
Thickness of plate	h =	0.5	0.85	m
Effective thickness of foot plate	d = h -d' =	0.4095	0.7595	m
Width shear of punch plane at x	$c_1 = b_x + d$ =	1.0095	1.3595	m
Width shear of punch plane at y	$c_2 = b_y + d$ =	1.0095	1.3595	m
Area of shear punch	A_p= $2(c_1+c_2)d$ =	1.65356	4.130161	m
Width of shear punch	$b_p = 2(c_1 + c_2)$ =	4.038	5.438	m
Ratio of longer side to near side column	$\beta_c = b_x/ b_y$ =	1.0	1.0	-
Stress of punch shear, taken minimum	f_p= $[1+2/\beta_c]$. (f'c^0,5/6)=	2.519	2.519	MPa
Quality of concrete K-300	f_p= $[\alpha_s(d/b_p)+2].(f'c^{0,5}/12)$	2.543	3.185	MPa
Used shear stress of punch into account	f_p =	2.519	2.519	MPa
Reduction factor of punch shear	φ =	0.75	0.75	-
Used shear stress of punch	$\varphi.V_{np} = \varphi.A_p.10^{3}$ =	1240.17	3097.6	kN
Checked strength criteria		No. safe	Safe	

Table 3. Stress calculation results at the button foundation

Description	Equation	Result	Unit
Vertical total loads	$P_{uv} =$	2,017.00	kN
Moment at direction x	$M_x =$	239.70	kNm
Moment at direction y	$M_y =$	238.60	kNm
Width foot of foundation	B =	2.00	m
Length foot of foundation	L =	2.00	m
Moment inertia at direction x	$I_x = 1/12.B.L^3 =$	1.33	m^4
Moment inertia at direction y	$I_y = 1/12.B^3.L =$	1.33	m^4
Gravity center of foot foundation at direction x	x = B/2	1.00	m
Gravity center of foot foundation at direction y	y = L/2	1.00	m
Width of column at direction x	$b_x =$	0.6	m
Width of column at direction y	$b_y =$	0.6	m
Eccentricity at direction x	$e_x = B/2 - (M_y/P_{uv}) =$	0.88	m
Soil stress maximum	$\sigma_{max} = (P_{uv}/A)+M_x.y/I_x + M_y.x/I_y =$	863.0	kN/m^2
Allowable net soil stress	$q_{an} =$	1,677.6	kN/m^2
Checked soil stress: $\sigma_{max} \leq q_{an}$	863 < 1,677.6 (safe)		

Figure 5 shows the results of the evaluation of the foundation sole reinforcement. After conducting research and recommendations to continue building construction work, work on the foundation structure was modified the footing as shown in Figure 6. The results of the implementation of the current mother and children building which has been used by the management of the Chasan Boisoirie Hospital Ternate are shown in Figure 7.



(a) (b)

Figure 5. Detailed of shallow foundation reinforcement after modified in this study: (a) Top view of footing reinforcement, (b) Bottom view of footing reinforcement

(a) (b)

Figure 6. Foundation design structure after modification in this study;
(a) Planned in design foundation, (b) Detailed reinforcement after modification

Figure 7. Documentation evidence of constructed building on using shallow foundation modification

CONCLUSION

The amount of loading on the superstructure due to external influences on multy-storey buildings has met the requirements (SNI, 2012). The design of multy-storey building shear walls has been done accordingly (SNI, 2013). Field tests have been carried out using the CPT test method and have combined checking and sampling to determine the mechanical properties of the soil in the laboratory with a depth of hard soil up to (Df) of 4.6 meters with a cone tip resistance (qc) of 250 kg/cm^2. This research has found that the sub-foundation structure is designed to use a shallow foundation, this does not meet the criteria, namely (λ) of 1.8, it should be less than one point zero. This requires a review of the design, because it can pose a risk of failure in the shear strength of the footing. Therefore, in this research modification of the shallow foundation has been carried out into a deep foundation. The results of the calculation of the shear strength of the modified foundation soles show more than 1.5 times more than the shallow foundation soles, so it can be concluded that the modified Deep Foundation model can be used as a method for solving shallow foundation design problems for four-storey buildings. This study can be suggested that to design shallow foundation, it must be satisfied to the criteria of external of footing capacity and internal stability of concrete quality. Moreover, in case foundation design of multy-stories building, then substructure should be used a deep foundation method.

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