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Review of The Structure of The Bored Pile and Pile CAP The Premiere MTH Project

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ABSTRACT

The Premiere MTH is an apartment complex located in South Jakarta, constructed on land with a hard soil layer extending deeper than 16 meters. Given these conditions, a bored pile foundation was selected as the optimal solution. This foundation type can be tailored to the necessary depth while minimizing disruption to nearby structures during installation. A bored pile is a type of deep foundation created by drilling into the ground to a specified depth. The process involves drilling a hole with specialized equipment, inserting a steel reinforcement cage, and then pouring concrete into the hole. Special tools are used to lift and position the casing and reinforcement. Once the concrete is poured, the casing is removed. According to the design analysis, the bored pile foundations used in this project have a diameter of 800 mm, with varying depths of 30 m and 35 m.

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1. INTRODUCTION

To meet the demands of building construction, effectiveness and efficiency are key considerations, with every step aimed at achieving the best possible outcomes in both quality and quantity. As a result, many new innovations have emerged, particularly in construction methods focused on improving efficiency. These advancements are expected to significantly contribute to fulfilling these requirements [1], [2]. The design of multi-storey buildings, including banks, offices, shops, and other commercial establishments, must adhere to technical standards, ensuring the structures are strong, rigid, and stable. Therefore, expertise is essential in both the design and construction processes to ensure a sense of safety and comfort for occupants, whether through the provision of adequate facilities or crime prevention measures. Additionally, high-rise buildings must offer protection from natural disasters such as floods, earthquakes, and storms [3], [4].

The structure of The Premiere MTH building is divided into upper and lower sections. The upper structure includes slabs, beams, columns, and roof components, while the lower structure consists of the foundation and pile caps [5]. The foundation is a critical part of the building's structural system, as it provides the base on which the entire structure rests. Without a proper foundation, the building would lack the necessary strength and stability for safe occupancy. The foundation bears the load and transfers it to the ground, causing pressure or soil stress around it. Therefore, in the planning phase, factors such as soil type, soil bearing capacity, the superstructure, and the project location must be considered. The choice of foundation type, whether shallow or deep, is determined by the project's specific requirements [6]–[8].

According to [7], [9] common issue in buildings is settlement. To prevent this, the foundation design must be accurately calculated to withstand the forces exerted by the upper structure. Drilled pile foundations offer a solution to this problem by distributing the loads into deeper soil layers. To identify the location of the hard soil layer, a sondir test or Cone Penetration Test (CPT) is conducted, which serves as the foundation for determining the bearing capacity of the drilled piles [10].

2. METHOD

The research method employed to evaluate the structure of the drilled foundation (bored pile) and pile cap for The Premier MTH Project utilizes a programming application based on structural analysis, specifically ETABS Non-Linear v.19. This method involves analyzing both the upper and lower structures of the building, with a focus on reinforced concrete elements. The analysis will encompass the design of beams, columns, floor slabs, and shear walls. The data for the Non-Linear ETABS structural analysis v.19 is derived from a case study layout of The Premier MTH Project, situated in Tebet, South Jakarta, which serves as offices, apartments, and retail spaces [5], [11]. Both bored pile foundations and pile-raft foundations must be designed to support the loads imposed by the superstructure. Article 7.1.5 of SNI-1726:2019 states that the foundation must be designed to be stronger than the upper structure. The alternative design requirements for the building structures in The Premier MTH Project are based on several standards: SNI-2847:2019, which outlines the requirements for structural concrete in buildings; SNI-1726:2019, which provides guidelines for earthquake resistance in building and non-building structures; SNI-1727:2019, which serves as a reference for determining the weight supported by the structure; and PBI 1971, which details the calculations for the moments acting on the floor slab [4].

2.1. Data Collection

2.1.1. Building Structure

The building structure includes information about the types of materials used, the layout and organization of structural elements such as beams, columns, slabs, and walls, as well as any specific architectural features. Moreover, it may outline the intended function of the building. The design criteria used for safety and stability, and compliance with relevant codes and standards. Overall, this section aims to give a clear understanding of how the building is constructed and how its structure supports its intended use by following Table 1.

Table 1. Building description

Structure Description	
The project name	The Premier MTH
Structural system	Dual system
Building function	Offices, apartments and retail
Number of floors	Office building: 14 layers + roof Apartment building: 17 layers + roof 3 ply basement floors
Number of basement floors	3 Floor
Height from the ground	+ 67 m
High below the ground	- 10,1 m
Typical floor height	3,2 m
Basement area 1	4322,613 m^2
Basement area 1I	4967,875 m^2
Basement area 1II	4967,875 m^2
The total area of the building including the basement	59.714,417 m^2

Source: Own studied (2022)

2.1.2. Land Data

To finalize this project, the necessary soil investigation data includes the N-SPT test results. Samples were collected from three locations where the N-SPT tests were conducted, focusing on the deepest layers of hard soil. The soil data consists of the N-SPT test results, which are essential for designing both the upper and lower structures of the building.

2.1.3. Structural Material

2.1.3.1 Concrete

The structure of this building is designed using reinforced concrete, with the characteristic strength of the concrete represented as fc', based on the strength of a cylinder at 28 days of curing. The parameters and definitions of the materials are determined using software. Below are the specifications for the concrete materials used for both the foundations and the superstructure in Table 2.

Table 2. Concrete materials

Concrete Materials	
Beams and plates	30 Mpa – 35 Mpa
Column and shear wall	35 Mpa – 40 Mpa
Drill pile, pile cap and dwall	30 Mpa

Source: Own studied (2022)

2.1.3.2. Reinforcing Steel

Specifications of steel material for concrete reinforcement are as follows:

a. Diameter 10, 13, 16, 19, 22, 25, 29, 32 is the type and yield stress of fy steel using 420 Mpa test rods for all main structural reinforcement.
b. Steel's modulus of elasticity, Es = 200,000 Mpa.

2.1.3.3. Structural Elements

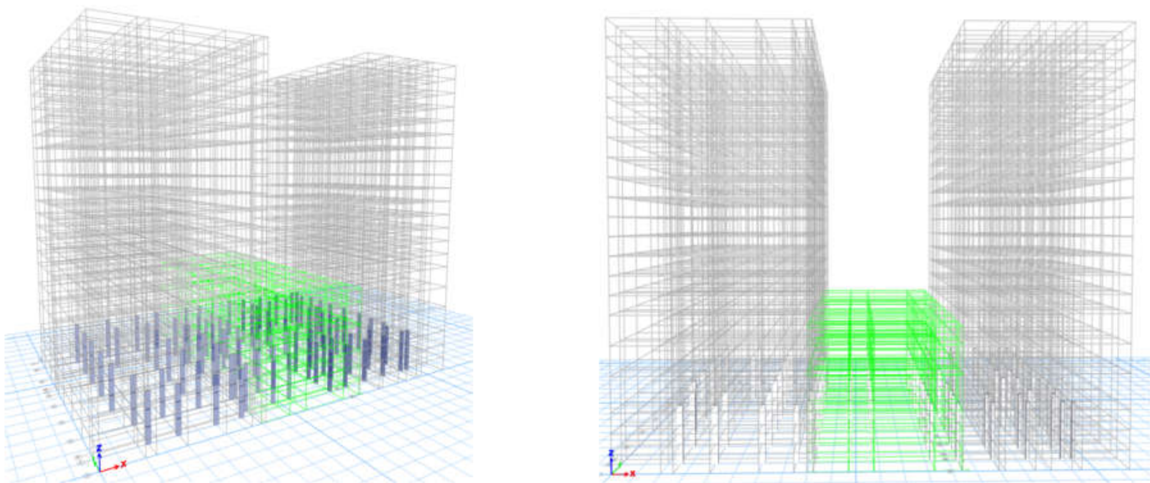
The structural components include beams, columns, floor slabs, core walls, and basement walls. The cross-sectional dimensions of these structural elements are presented in Table 3, which outlines the office column structure elements.

Table 3. Office column structure elements

Floor	Type Column (cm)						
	KK1A	**KK1B**	**KK2A**	**KK2B**	**KK3**	**KK4A**	**KK4B**
14-RF	60x70	60x70	50x80	50x80	60x80	60x80	60x80
12-13	60x70	60x70	50x80	50x80	60x80	60x80	60x80
10-11	60x80	60x80	50x90	50x90	60x80	60x90	60x90
8-9	60x90	60x90	50x100	50x100	60x90	60x100	60x100
6-7	60x90	60x90	50x100	50x100	60x90	60x100	60x100
4-5	60x90	60x90	50x100	50x100	60x90	60x100	60x100
3	60x90	60x90	50x100	50x100	60x90	60x100	60x100
GF - 2	60x90	60x90	50x100	50x100	70x100	60x100	60x100
B2 - B1	60x90	60x90	50x100	50x100	70x100	60x100	60x100

Source: Own studied (2022)

The structural elements are modeled in ETABS and displayed from a 3D perspective view in Figure 1(a) and the division of levels within the structure is illustrated in Figure 1(b).



(a) (b)

Figure 1. Structured elements (a) perspective 3d structure model (b) structure level division

2.1.3.4. Structure Loading

Structure loading pertains to the different forces and loads that a building or structure needs to withstand over its lifetime. Grasping these loads is essential for ensuring proper structural design and safety. The types of loads applied to the structural model include:

a. Structure dead load
   Structural dead load refers to the load generated by the total weight of the structure itself, derived from the materials used. When modeling the building structure, the specific gravity is automatically calculated by the ETABS V19 software based on the cross-sectional area and dimensions defined within the model.
b. Additional dead load (superimposed dead load)
   The additional dead load, also known as superimposed dead load, refers to the weight of all non-structural elements that are placed on and remain on the structure.
c. Life load
   Live load encompasses all loads generated by the occupancy or use of a building. This includes loads on the floors from movable items, as well as machinery and equipment that are not fixed parts of the structure and can be replaced throughout the building's lifespan, leading to variations in the loads on the floors or roof.

2.2. Research Stages

Gathering data and information necessitates obtaining supporting data related to the building's structure, which will be utilized as a case study for subsequent research phases. This secondary data includes shop drawings and local soil investigation data. Shop drawings serve as a reference for modeling 3D structures using the ETABS program, while the local soil data are used to assess the pressure exerted by the soil on the basement walls, evaluate ground surface acceleration parameters, and design the spectral response.

2.2.1. Structure Modeling

The first step in 3D modeling involves specifying the structural materials and the walls of the structure. Once the structural elements are defined, they are integrated into the structural model. Additionally, non-structural elements, such as floor coverings and non-structural walls, are considered as loads on the structure.

2.2.2. Calculation of Local Building and Land Aspects

a. Building Risk Category and Priority Factors
   Building risk categories and the importance factor are established based on the building's function and classified in accordance with SNI-1726-2019.
b. Response Modification Coefficient (R)
   The response modification coefficient is established based on the type of earthquake-resistant structural system and is defined according to SNI-1726-2019. This coefficient should be assessed by considering both the X and Y directions of the building structure.
c. Site Classification
   Site classification, as outlined based on geotechnical investigation results, specifically the average SPT value of the soil profile at a depth of 30 meters measured from the surface. The site class or soil type is determined according to article number 5.1 SNI 03-1726-2019.
d. Spectral Response Acceleration Parameter
   The spectral response acceleration parameters include a short period of 0.2 seconds (SDS) and a period of 1 second (SD1), which are derived from the 2010 Indonesian Earthquake Hazard Map, reflecting a 2% probability of occurrence for planned earthquakes over 50 years as specified in article number 4.1.1 of SNI 03-1726-2019 in detail on Figure 2.

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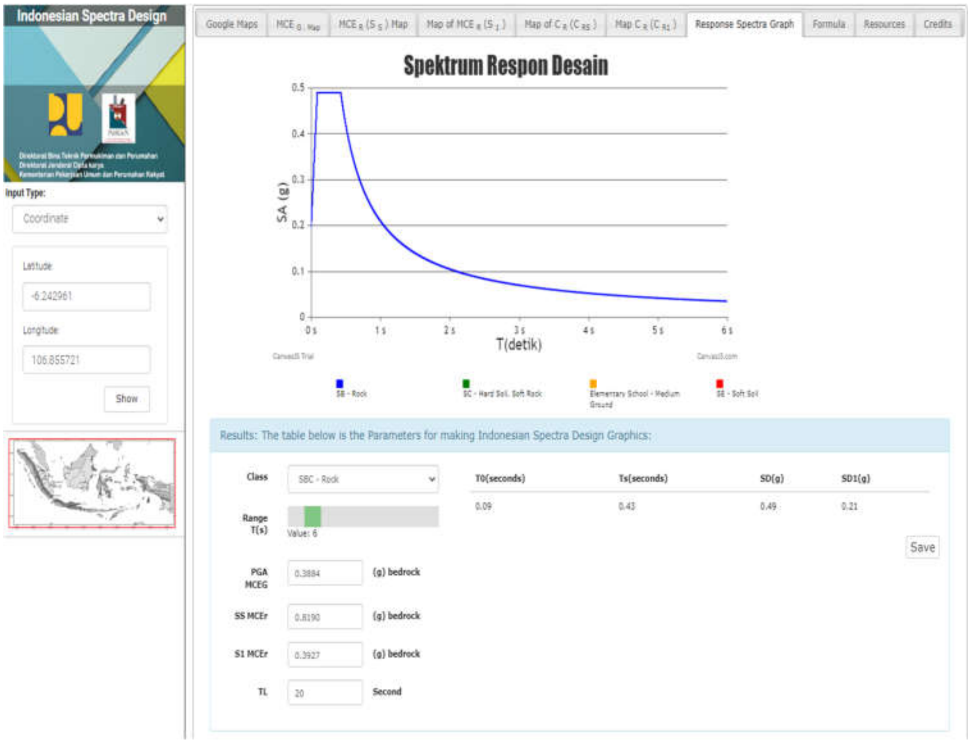

Figure 2. Design elastic spectrum response.

The values of SDS and SD1 are utilized to determine site coefficients (FA and FV). These site coefficients influence the calculation of the short-period acceleration response spectrum parameter (SMS), the one-second period acceleration response spectrum parameter (SM1), and the design spectral response acceleration parameter for the short period (SDS).

e. Structural Natural Vibration Period
   The natural vibration period of the structure can be derived from the results of the ETABS analysis or through approximation calculations. In the design, the value of the natural vibration period must not be less than Ta and should not exceed Tmax.
f. Seismic Base Slide
   The total base shear force acting at the base level of the structure (V1) is determined using the seismic response coefficient (CS), ensuring that its value does not exceed the maximum seismic response coefficient (CS_{max}) and is not lower than the minimum seismic response coefficient (CS_{min}).

3. RESULTS AND DISCUSSION

3.1. Earthquake Resistant Foundation Structure Design

The foundation structure of The Premiere MTH building comprises foundation piles and pile caps. Its primary function is to support the entire load of the building and transfer that load to the soil beneath. A foundation system must be capable of bearing the building's weight, along with external forces such as wind and earthquakes. Therefore, it is essential for the foundation to be strong and rigid to prevent settling or breaking, as repairing a foundation system that is embedded in the ground can be quite challenging.

3.2. Earthquake Resistant Foundation Requirments

The Premiere MTH project, situated in South Jakarta, falls under seismic design category E. Consequently, the foundation must be designed in compliance with Indonesia's applicable national standards, including SNI-1726-2019 for planning earthquake resistance in building and non-building structures, SNI-1727-2013 for minimum load requirements in building design, and SNI-2847-2019 for structural concrete requirements in buildings.

Article 7.14.2.2.2 of SNI-1726-2019 about pile foundation, states that when using concrete piles in site classes SA to SD, the piles must include longitudinal reinforcement as well as continuous transverse reinforcing bars throughout their length. The longitudinal and transverse reinforcement should extend seven times the diameter of the pile from the pile cover and from the contact surface between the hard or firm layer and any potentially liquefiable layer or soft clay and semi-firm clay. If transverse reinforcement is absent along the length of the reinforcement, a minimum transverse spiral reinforcement ratio of at least half of the specified amount above is permitted.

3.3. Aspect of Local Buildings and Land Against Earthquakes

3.3.1. Building Risk Category and Building Priority Factors

a. Building risk category
   The building risk category is established based on the building's function, as classified in Table 2.2 or Table 1 of SNI-1726-2019 is classified as II.
b. Building priority factors
   The building priority factor is established based on the building risk category, as outlined in Table 2.3 or Table 2 of SNI-1726-2019 is classified as I.

3.3.2. Response Modification Coefficient (R)

The response modification coefficient is determined based on the type of structural system designed to resist earthquake forces, as outlined in Table 2.5 or 9 of SNI-1726-2012. For a dual structure that combines Special Moment Frames with Special Reinforced Concrete Shear Walls, the response modification coefficient (R) is 7.

3.3.3. Site Classification

Site classification, detailed in Article 5.1 of SNI 03-1726-2012, is used to establish the seismic design category and the parameters for the earthquake acceleration spectral response, mapped as (SS and S1). The results of geotechnical investigations conducted at the premiere construction site were analyzed based on the subsoil profile up to 30 meters, as presented in Table 4.

Table 4. SPT value of layer soil

Depth (m)	di (m)	di/Ni				
		SPT 1	SPT 2	SPT 3	SPT 4	SPT 5
1.5	1.5	0.500	0.300	0.188	0.214	0.300
3.0	1.5	0.750	0.375	0.214	0.375	0.167
4.5	1.5	0.500	0.500	0.750	0.500	0.750
6.0	1.5	0.300	0.375	0.500	0.188	0.500
7.5	1.5	0.188	0.188	0.375	0.167	0.300
9.0	1.5	0.125	0.500	0.250	0.071	0.750
10.5	1.5	0.035	0.150	0.041	0.060	0.375
12.0	1.5	0.058	0.188	0.065	0.056	0.150
13.5	1.5	0.054	0.115	0.088	0.065	0.083
15.0	1.5	0.060	0.060	0.042	0.079	0.079
16.5	1.5	0.058	0.025	0.025	0.088	0.037
18.0	1.5	0.056	0.025	0.025	0.071	0.025
19.5	1.5	0.037	0.025	0.025	0.033	0.025
21.0	1.5	0.043	0.025	0.025	0.029	0.025
22.5	1.5	0.025	0.025	0.025	0.025	0.025
24.0	1.5	0.036	0.025	0.025	0.028	0.035
25.5	1.5	0.032	0.025	0.025	0.027	0.052
27.0	1.5	0.033	0.050	0.039	0.026	0.060
28.5	1.5	0.042	0.060	0.058	0.054	0.058
30.0	3.0	0.048	0.063	0.045	0.060	0.041

3.3.4. Spectral Response Acceleration Parameter

The spectral response acceleration parameters include a short period of 0.2 seconds (SDS) and a 1-second period (SD1), both exhibiting 5% damping, in accordance with Article 4.1.1 of SNI-03-1726-2012. The average of parameter response spectra, SPT value for Soil Criteria (Site E) over the top 30 meters is calculated as:

SD1 = 0.639

SS = 0.795

S1 = 0.399

Fa = 1.264
Fv = 2.405
T_0 = 0.191
Ts = 0.954

3.3.5. Combination of Structural Loading with Considering Earthquake Area

For the design of the concrete superstructure, compliance with SNI 2847:2013 and SNI 1726:2012 is required, considering the impacts of vertical earthquakes and redundancy factors with the details below:
U = 1,4 D
U = 1,2 D + 1,6 L
U = (1,2 + 0,2 SDS) D + 0,5 L + ρ.QE (for L ≤ 4,80 kPa)
U = (1,2 + 0,2 SDS) D + L + ρ.QE (for L ≥ 4,80 kPa and parking)
U = (0,9-0,2 SDS) D + ρ.QE

<u>For elements subjected to earth pressure</u>
U = 1,2 D + 1,6 L + 1,6 H
U = 0,9 D + 1,6 H
with the details of each symbol are:
U = ultimate load combination (strong need)
D = dead load
L = live load with reduction
QE = earthquake load 100% main direction + 30% perpendicular direction
H = lateral earth pressure, with and without H
SDS = design response spectrum acceleration parameter in short period
ρ = structure redundancy factor, if required according to the provisions

3.4. Lower Structure Element Design

Substructure elements are classified as components of the structure located below ground level, as they are supported by the soil and serve as the foundation for the upper structural elements.

3.4.1. Bored Pile Planning

Bored piles are a type of pile foundation designed for multi-story buildings, and they are regarded as an optimal solution for supporting loads in critical conditions.

a. Soil investigation
Soil investigation is essential for assessing the technical properties of the soil, which is crucial for analyzing bearing capacity and soil settlement. Field investigations are conducted using the Standard Penetration Test (SPT), as obtaining undisturbed soil samples from granular soils can be challenging. Below are the results from the field soil investigation tests.

b. Soil bearing capacity
The bearing capacity of the soil is determined to find both the compressive and tensile bearing capacities based on the Standard Penetration Test (SPT) values obtained in the field, utilizing the Meyerhof method about carrying capacity of press permission and carrying capacity of pull permit where the following formula:
Pa = bearing capacity of compressive strength
Pta = carrying capacity of the tensile permit
Qc = 20 N, for silt/clay and 40 N, for sand

N = N-SPT value
Ap = cross-sectional area of the pile
Ast = perimeter of the cross section of the pile
Li = Length of the pile segment under consideration
D = depth of soil under consideration
Wp = pole weight
Fi = shear force on the pile segment blanket with N maximum 12 tons/m2, for silt/clay and N/5 maximum 10 tons/m2, for sand
FK 1, FK2 = safety factor, 3 and 5.

Table 5. Recommendation of foundation bearing capacity according to geotechnical report

Pole diamter (cm)	C.O.L (m)	L_{eff} (m)	Soil boring	Q friksi (ton)	Q end-bearin (ton)	Weight pole (ton)	Q-press permission (ton)	Q-pull permit (ton)
80	-12.5	22	BH-1	694	154	27	339	221
			BH-2	742	101	27	337	234
			BH-3	819	177	27	398	256
			BH-4	719	153	27	349	228
			BH-5	683	105	27	315	218
			Average				348	231
			Design				320	220

c. Load Grouping
The foundation load is derived from the analysis performed using ETABS software, which serves as the foundation design basis. The calculation of foundation requirements for a single point is determined by dividing the vertical reaction value (Fz) by the soil's bearing capacity for one pile and multiplying by a reduction factor.

d. Mast Group Configuration and Efficiency Design
The configuration of the pile group is designed to meet force compliance requirements, requiring that the minimum spacing between foundation piles should be 2.5 times the pile diameter for end-bearing piles and 3 meters for friction piles. In the context of bored pile foundations, the primary reference for strength is the end-bearing pile, which results in a spacing of 2.4 times the pile diameter.

3.4.2. Pile Cap Structure Planning

The main function of a pile cap is to create a solid foundation for the vertical loads exerted by the superstructure display in Figure 3. It plays a crucial role in minimizing differential settlement among the piles and guarantees an even distribution of loads. By linking several piles, the pile cap lowers the likelihood of excessive displacement or structural failure, especially in regions prone to dynamic forces like earthquakes or strong winds following Table 6.

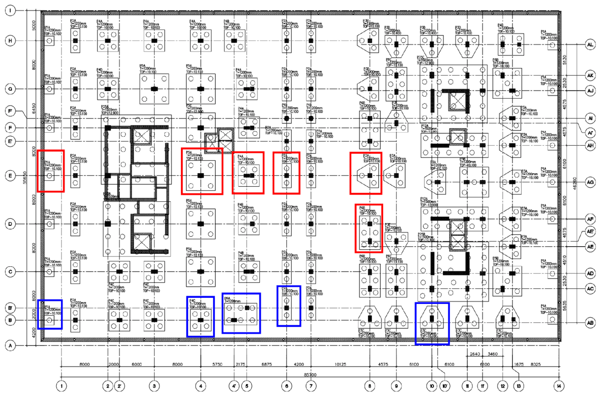

Figure 3. Pile Cap Plan

Table 6. Pile cap structure calculation

Pile Cap	Position	b (mm)	h (mm)	d (mm)	θ	Mn (kg.m)	Size Asreq (mm^2)	D	S_Req	S	ρ	Φ. Mn	Pile Cap Reinforcement	Check	Ratio
P1A	Perimeter	1000	1200	1093	0.8	40127	1080	19	262.7	100	0.0026	104227	D19 - 100 mm	OK	0.39
P2A	Perimeter	1000	1200	1093	0.8	80255	2175	19	130.4	100	0.0026	104227	D19 - 100 mm	OK	0.77

P3A	Perimeter	1000	1200	1093	0.8	105558	2873	25	170.9	150	0.0030	119952	D25 - 150 mm	OK	0.88
P4A	Perimeter	1000	1200	1093	0.8	160509	4414	25	111.3	100	0.0045	177984	D25 - 100 mm	OK	0.90
P6A	Perimeter	1000	1200	1093	0.8	153066	4203	25	116.8	100	0.0045	177984	D25 - 100 mm	OK	0.86
P1A	Center	1000	1200	1093	0.8	70223	1899	25	258.6	100	0.0045	177984	D25 - 100 mm	OK	0.39
P2A	Center	1000	1200	1093	0.8	140445	3848	25	127.6	100	0.0045	177984	D25 - 100 mm	OK	0.79
P3A	Center	1000	1200	1093	0.8	147727	4053	25	121.2	100	0.0045	177984	D25 - 100 mm	OK	0.83
P4A	Center	1000	1200	1093	0.8	131708	3602	25	136.3	100	0.0045	177984	D25 - 100 mm	OK	0.74
P5A	Center	1000	1200	1093	0.8	145947	4003	25	122.7	100	0.0045	177984	D25 - 100 mm	OK	0.82
P6B	Center	1000	1200	1093	0.8	163746	4506	25	109.0	100	0.0045	177984	D25 - 100 mm	OK	0.92

3.4.3. Bored Pile Structural Planning

Bored piles, commonly referred to as drilled shafts, are a form of deep foundation utilized to support structures when the soil's load-bearing capacity is inadequate at shallow depths. The structural planning for bored piles encompasses several essential steps and factors that are crucial for maintaining the stability, strength, and safety of the entire structure as follow in Figure 4.

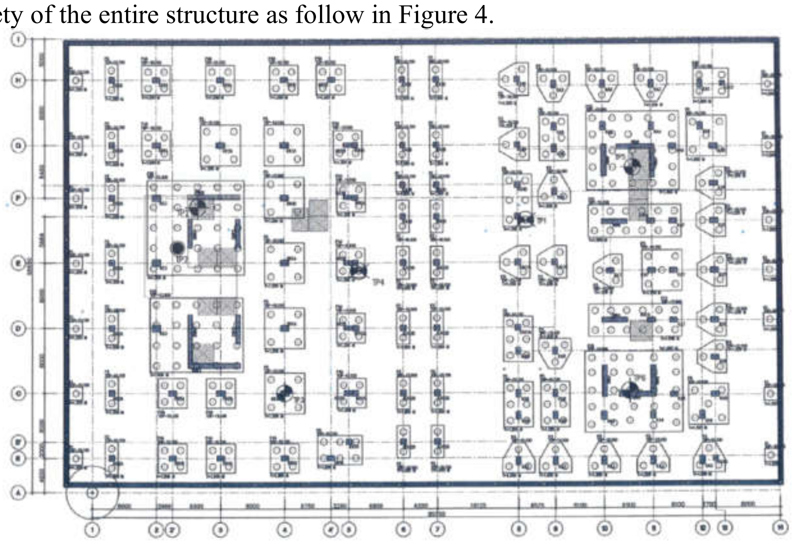

Figure 4. Bored pile plans reviewed for analysis and design

The calculation of the bored pile structure is presented in the following Table 7, with detailed calculations and graphical representations provided in the subsequent attachment.

Material quality

fc = 30.0 M.Pa

ec = 4351.1 M.Pa

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fy = 420.0 M.Pa

Table 7. Calculation of the bored pile structure

Bored Pile Segment	d (mm)	Rebar	Spiral	Ag (mm^2)	Ast (mm^2)	εs=fs=0		fs=-0.5fy	
						ØPn (kN)	ØMn (kN.m)	ØPn (kN)	ØMn (kN.m)
0 m s/d 5 m	800	24 - D22	D13 - 80 mm	502654.82	9123.19	6675.63	816.40	4557.06	1037.78
5 m s/d 10 m	800	10 - D22	D13 - 250 mm	502654.82	3801.33	5888.33	658.42	4200.12	797.96
10 m s/d 22 m	800	7 - D22	D13 - 250 mm	502654.82	2660.93	5719.62	624.56	4123.63	746.57
0 m s/d 5 m	800	18 - D22	D13 - 80 mm	502654.82	6842.39	6338.22	748.69	4404.08	935.00
5 m s/d 10 m	800	10 - D22	D13 - 250 mm	502654.82	3801.33	5888.33	658.42	4200.12	797.96
10 m s/d 22 m	800	7 - D22	D13 - 250 mm	502654.82	2660.93	5719.62	624.56	4123.63	746.57

4. Conclusion

After completing the design process for the earthquake-resistant foundation structure at The Premiere Building, in accordance with SNI 1726:2012, SNI 1727:2013, and SNI 2847:2013, the following conclusions were drawn:

1. The dimensions of the bored pile foundation are as follows: a. The diameter of the bored pile foundation is 80 cm with a length of 22 meters (measured from the bottom of the pile cap). This pile has a compressive capacity of 320 tons and a tensile capacity of 220 tons.
2. The reviewed pile cap on the raft foundation (Bored Pile – Raft Foundation) has a thickness of 1200 mm. The configuration of the Bored Pile and Raft Foundation is illustrated in the Figure 5.

Figure 5. Bored pile – raft foundation configuration at the premiere MTH building

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