Application of the Meyerhoff and De Beer Methods in Evaluating Soil Bearing Capacity for Low-Rise Building Foundation Design

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Abstract

Foundation design for low-rise buildings requires an accurate evaluation of soil bearing capacity in order to obtain a foundation solution that is both safe and economical. This study applies the Meyerhoff method to evaluate the bearing capacity of shallow foundations and the De Beer method to evaluate the bearing capacity of deep foundations (driven piles and bored piles), based on Sondir/DCPT (Dutch Cone Penetration Test) data from the rehabilitation project of the BKKBN Regional Office Building of North Sumatra Province on Jl. Gn. Krakatau, Medan City. Two sondir points (S-1 and S-2) were tested using a 2.5-ton capacity apparatus following standard procedures, reaching maximum depths of 5.40 m and 4.60 m with cone resistance (CR) values of 209 kg/cm² and 205 kg/cm², both classified as very dense soil. Application of the Meyerhoff method (Qa = CR/40) for footing sizes ranging from 125×125 cm² to 200×200 cm² shows that for a typical column load of 15-20 tons in a 2-3 story building, a 150×150 cm² shallow footing only becomes sufficient at a depth of ≥ 3.00 m at point S-1, while at point S-2 this capacity is already reached at a depth of 2.00 m. Application of the De Beer method for 40 cm diameter piles shows that driven pile capacity is consistently 7-8% higher than bored pile capacity at the same diameter, and to reach a design load of 50 tons, point S-1 requires a pile depth of ≥ 5.00 m, whereas at point S-2 this capacity is already achieved at a depth of 4.00 m. These results demonstrate that combining the Meyerhoff and De Beer methods, applied to the same sondir dataset, can provide practical, site-specific guidance for engineers in selecting the appropriate foundation dimension and depth for low-rise buildings.

Keywords: Meyerhoff Method, De Beer Method, Soil Bearing Capacity, Low-Rise Building Foundation, Sondir (DCPT)

Introduction

A foundation is the structural element that transfers all building loads, including dead load, live load, and dynamic load, directly to the underlying soil layer. Before a foundation can be properly designed, the bearing capacity and characteristics of the underlying soil must first be determined through a soil investigation. One of the most widely used field methods in Indonesia for shallow-to-medium depth soil investigation is the Sondir test, also known as the Dutch Cone Penetration Test (DCPT), which measures cone resistance (CR) and total skin friction (TSF) at every 20 cm interval of penetration.

For low-rise buildings (1-3 stories) such as office buildings, schools, or public service facilities, selecting the appropriate foundation type strongly determines construction cost efficiency and schedule performance. Two soil bearing capacity analysis methods based on sondir data that are commonly used in Indonesian engineering practice are the Meyerhoff method for evaluating shallow (spread) foundations, and the De Beer method for evaluating deep foundations (driven piles and bored piles). This study is based on a soil investigation report for the rehabilitation project of the BKKBN (National Population and Family Planning Board) Regional Office Building of North Sumatra Province, located on Jl. Gn. Krakatau, Kelurahan Pulo Brayan Darat II, Kecamatan Medan Timur, Kota Medan. Two sondir points (S-1 and S-2) were tested to a target depth of 20.00 m using a 2.5-ton capacity sondir apparatus, but both points were terminated earlier once the cone resistance exceeded 200 kg/cm², indicating that a very dense soil layer had been reached. This study aims to apply the Meyerhoff and De Beer methods simultaneously to the same sondir dataset, in order to evaluate soil bearing capacity at various depths and foundation dimensions, and to provide a practical illustration of appropriate foundation type and depth selection for typical column loads of low-rise buildings.

Literature Review

2.1. Foundations for Low-Rise Buildings

Low-rise buildings generally have column loads that are relatively small to moderate compared to high-rise buildings, making foundation-type selection an important decision between cost efficiency (shallow foundation) and long-term settlement safety (deep foundation). According to Hardiyatmo [1], foundation-type selection must be based on the depth of the hard soil layer, the magnitude of the structural load, and groundwater conditions, rather than habit or preference without technical evaluation. Sondir (DCPT) data is one of the primary data sources used to calculate soil bearing capacity, whether through the Meyerhoff approach for shallow foundations or the De Beer approach for deep foundations.

2.2. The Meyerhoff Method for Shallow Foundations

Shallow foundations (footings) are typically used when a soil layer with adequate bearing capacity is found at a relatively shallow depth. Based on the Meyerhoff approach derived from sondir results, the allowable bearing capacity, disregarding footing width, is expressed as $Qa = CR/40$, where Qa is the allowable bearing capacity for a settlement of 2.54 cm (kg/cm²) and CR is the cone resistance (kg/cm²). Fauzi and Ikhya [2] analyzed the influence of hard-soil depth and footing width on the bearing capacity of continuous shallow foundations using PLAXIS 2D, concluding that wider footings increase bearing capacity but are also more sensitive to groundwater table depth. Muda [3] compared sondir-based bearing capacity with laboratory-derived values, finding that shallow foundation capacities obtained from sondir data were generally lower and more conservative than laboratory-based calculations. Ahmad [4] compared the L'Heminier and Meyerhoff methods for shallow foundation design based on two sondir points and found that both methods yielded sufficient bearing capacity where hard soil occurred within 2.6-2.8 m depth, allowing the use of shallow foundations for cost and schedule efficiency.

2.3.The De Beer Method for Deep Foundations

Deep foundations, such as driven piles and bored piles, are used when the soil layer with adequate bearing capacity lies beyond the practical depth of shallow footings, or when the structural load exceeds the shallow foundation's allowable capacity. The De Beer method, derived directly from sondir data, calculates the allowable bearing capacity of a driven pile as $Qa = (CR.F)/3 + (TSF.O)/5$, and for a bored pile as $Qa = (CR.F)/3$, where F is the cross-sectional area of the pile and O is the perimeter of the pile section. The absence of the skin-friction term in the bored-pile formula reflects the reduced shaft resistance typically observed in drilled piles, where the surrounding soil is disturbed during excavation rather than densified as in pile driving. Mardianti, Nuklirullah, and Dwina [5] applied the Aoki-De Alencar and Schmertmann-Nottingham methods on sondir data for a hospital building project in Jambi and obtained allowable single-pile bearing capacities ranging from 63 to 200 tons depending on pile grouping. Nugraha and Harahap [6], studying a project in Medan Tembung, Medan City, compared the Meyerhoff and Aoki-De Alencar methods for driven piles based on combined CPT and SPT data and found that the Meyerhoff method consistently produced higher single-pile capacities than the Aoki-De Alencar method. Sulistianto and Rus [7] used N-SPT and sondir data to recommend deep foundations for a warehouse project in Kutai Kartanegara once the design load exceeded the shallow soil's bearing capacity, while Anggreana, Elizar, and Pratama [8] showed that foundation-type recommendations can differ between sondir points within the same project site, depending on the depth of hard soil found at each point.

Research Methodology

3.1. Location and Field Data

The soil investigation was conducted at the rehabilitation site of the BKKBN Regional Office Building of North Sumatra Province, located on Jl. Gn. Krakatau, Kelurahan Pulo Brayan Darat II, Kecamatan Medan Timur, Kota Medan, Provinsi Sumatera Utara. Two sondir/DCPT points (S-1 and S-2) were tested using a light sondir apparatus with a capacity of 2.5 tons, in accordance with [9] and [10]. At each 20 cm interval, the total resistance (TR) and cone resistance (CR) were recorded, from which the friction resistance ($FR = TR - CR$), skin friction ($SF = FR \times 20/10$), total skin friction ($TSF = \Sigma SF$), and local skin friction ($LSF = FR/10$) were derived.

3.2. Meyerhoff Method Formula

The allowable bearing capacity of a shallow (spread) foundation, disregarding footing width, is calculated using:

$$Qa = CR / 40$$

where Qa is the allowable bearing capacity for 2.54 cm settlement (kg/cm²) and CR is cone resistance (kg/cm²). This value is then multiplied by the footing area to obtain the total allowable load (kg) for footing sizes of 125×125, 150×150, 175×175, and 200×200 cm².

3.3. De Beer Method Formula

The allowable bearing capacity of a driven pile is calculated using:

$$Qa = (CR \, . \, F)/3 + (TSF \, . \, O)/5$$

while the allowable bearing capacity of a bored pile is calculated using:

$$Qa = (CR \, . \, F)/3$$

where Qa is the pile bearing capacity (kg), CR is cone resistance (kg/cm²), TSF is total skin friction (kg/cm), F is the pile cross-sectional area (cm²), and O is the pile perimeter (cm). Both formulas incorporate safety factors of 3 (end bearing) and 5 (skin friction), consistent with common Indonesian geotechnical practice for sondir-based pile design [1].

3.4. Application Analysis Procedure

The application of both methods was carried out through: (1) calculating shallow foundation bearing capacity using the Meyerhoff method at depths of 0-3.00 m, the practical depth range for shallow foundation application; (2) calculating driven pile and bored pile bearing capacity using the De Beer method at 30 cm and 40 cm diameter across the full available sondir depth; and (3) comparing the results against typical low-rise building column loads (assumed at 15-20 tons for shallow foundations and 50 tons for deep foundations), in order to determine the minimum foundation depth and dimension that satisfies the requirement at each sondir point.

Results

4.1. Summary of Sondir Data

The soil investigation results at both sondir points indicate a soil profile that becomes progressively denser with depth, reaching the "very dense" classification ($CR \geq 200$ kg/cm²) before the planned depth of 20.00 m was reached, as summarized in Table 1.

Table 1. Summary of Sondir/DCPT Results

Parameter	S-1	S-2
Planned depth (m)	20.00	20.00
Groundwater level/GWL (m)	-4.10	-4.00
Maximum depth achieved (m)	5.40	4.60
Maximum cone resistance, CR (kg/cm²)	209	205
Total skin friction, TSF (kg/cm)	262	252
Soil density classification	Very dense	Very dense

4.2. Application of the Meyerhoff Method for Shallow Foundations

Using the formula $Qa = CR/40$, the allowable bearing capacity of shallow footings at depths of 1.00, 2.00, and 3.00 m is presented in Table 2 (point S-1) and Table 3 (point S-2).

Table 2. Shallow Foundation Bearing Capacity - S-1 (kg)

Depth (m)	CR (kg/cm^2)	125×125 cm^2	150×150 cm^2	175×175 cm^2	200×200 cm^2
1.00	12	4,687.50	6,750.00	9,187.50	12,000.00
2.00	21	8,203.13	11,812.50	16,078.13	21,000.00
3.00	82	32,031.25	46,125.00	62,781.25	82,000.00

Table 3. Shallow Foundation Bearing Capacity - S-2 (kg)

Depth (m)	CR (kg/cm^2)	125×125 cm^2	150×150 cm^2	175×175 cm^2	200×200 cm^2
1.00	15	5,859.38	8,437.50	11,484.38	15,000.00
2.00	68	26,562.50	38,250.00	52,062.50	68,000.00
3.00	61	23,828.13	34,312.50	46,703.13	61,000.00

It is noteworthy that at point S-2, the bearing capacity value decreases from 68,000 kg at 2.00 m to 61,000 kg at 3.00 m for the 200×200 cm^2 footing, reflecting a locally softer soil lens rather than a continuously increasing trend, consistent with the fluctuating CR values recorded in the field data.

4.3. Application of the De Beer Method for Deep Foundations

The allowable bearing capacity of driven piles and bored piles at 30 cm and 40 cm diameter, calculated using the De Beer method across the full sondir depth, is presented in Table 4 (S-1) and Table 5 (S-2).

Table 4. Deep Foundation Bearing Capacity - S-1 (kg)

Depth (m)	CR	TSF	Pile 30cm	Pile 40cm	Bore 30cm	Bore 40cm
1.00	12	12	3,052.08	5,325.44	2,826.00	5,024.00
2.00	21	34	5,586.06	9,646.08	4,945.50	8,792.00
3.00	82	74	20,705.16	36,189.55	19,311.00	34,330.67
4.00	77	130	20,582.70	35,502.93	18,133.50	32,237.33
5.00	177	220	45,828.30	79,630.40	41,683.50	74,104.00

Depth (m)	CR	TSF	Pile 30cm	Pile 40cm	Bore 30cm	Bore 40cm
5.40 (max)	209	262	54,155.58	94,082.77	49,219.50	87,501.33

Table 5. Deep Foundation Bearing Capacity - S-2 (kg)

Depth (m)	CR	TSF	Pile 30cm	Pile 40cm	Bore 30cm	Bore 40cm
1.00	15	12	3,758.58	6,581.44	3,532.50	6,280.00
2.00	68	48	16,918.32	29,675.09	16,014.00	28,469.33
3.00	61	112	16,475.58	28,352.11	14,365.50	25,538.67
4.00	137	186	35,767.74	62,029.65	32,263.50	57,357.33
4.60 (max)	205	252	53,025.18	92,156.91	48,277.50	85,826.67

At the same diameter, the driven pile consistently produces a higher allowable bearing capacity than the bored pile, by approximately 7-8% at the maximum tested depth (e.g., 94,082.77 kg vs. 87,501.33 kg at 40 cm diameter, point S-1). This difference is attributed to the absence of the skin-friction term in the bored-pile formula, which reflects soil disturbance during the drilling process compared to the densification effect of pile driving.

4.4. Illustration of Application for Low-Rise Building Design

To illustrate the practical application of both methods, a typical low-rise building (2-3 story) column load of 15-20 tons was assumed for the shallow foundation case, and a larger column load of 50 tons (e.g., a main structural column carrying additional equipment load) was assumed for the deep foundation case. Table 6 summarizes the minimum depth required at each sondir point for the calculated bearing capacity to satisfy that load.

Table 6. Minimum Foundation Depth to Satisfy the Illustrative Design Load

Foundation Type	Design Load	Point S-1	Point S-2
150×150 cm² footing (Meyerhoff)	15-20 tons	≥ 3.00 m (46.13 tons)	≥ 2.00 m (38.25 tons)
40 cm diameter driven pile (De Beer)	50 tons	≥ 5.00 m (79.63 tons)	≥ 4.00 m (62.03 tons)

These results show that at point S-1, the 150×150 cm² footing only satisfies the 15-20 ton design load at a depth of ≥ 3.00 m, since at 2.00 m its capacity is only 11.81 tons. In contrast, at point S-2 the 38.25-ton capacity is already reached at 2.00 m depth, allowing the shallow foundation to be placed at a shallower level at this point. A similar pattern is observed for deep foundations: a 40 cm diameter driven pile at point S-1 only reaches a 50-ton capacity at a depth of ≥ 5.00 m, close to the maximum depth successfully tested (5.40 m), whereas at point S-2 this capacity has already been exceeded at a depth of 4.00 m. This difference confirms that even though both sondir points lie within the same project site, the variation in soil profile between points is significant enough to affect the decision on foundation depth and dimension, indicating that the Meyerhoff and De Beer methods should be applied on a per-point basis rather than generalized across the entire building footprint. In general, for a low-rise building with moderate column loads such as in this case, a combination of shallow foundations at 2.00-3.00 m depth is adequate for most columns, while deep foundations may be selectively considered only for columns carrying larger concentrated loads.

Conclusion

The application of the Meyerhoff and De Beer methods to sondir (DCPT) data from two points (S-1 and S-2) at the rehabilitation project of the BKKBN Regional Office Building of North Sumatra Province in Medan City shows that both points reach the very dense soil classification (CR ≥ 200 kg/cm²) at relatively shallow depths of 5.40 m (S-1) and 4.60 m (S-2). For a typical low-rise building column load of 15-20 tons, the Meyerhoff method shows that a 150×150 cm² footing only satisfies the requirement at a depth of ≥ 3.00 m at point S-1, but already satisfies it at a depth of 2.00 m at point S-2. For a larger design load (50 tons), the De Beer method shows that a 40 cm diameter driven pile requires a depth of ≥ 5.00 m at point S-1, while at point S-2 this capacity is already reached at a depth of 4.00 m. Driven piles consistently produce 7-8% higher bearing capacity than bored piles of the same diameter, due to the soil densification effect during pile driving. These findings confirm that applying both methods simultaneously to the same sondir dataset provides more site-specific guidance than a generalized approach across an entire project area, and are consistent with similar studies conducted in Medan City and other regions of Indonesia [2]-[8], which emphasize the importance of evaluating soil bearing capacity on a per-sondir-point basis before finalizing the foundation type, dimension, and depth for low-rise buildings.

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