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Verifying Safe Load Carrying Capacity of End Bearing Piles at Site- from IS code to a simplified approach in formulation

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Abstract:

Piles are elements of deep foundation and carry loads of the problematic strata and structure to the beneath stable surface in a distributed way. The frictional part of the pile and skin effect carries the contact of the pile to the surrounding surface making it a good choice of geotechnical engineers. In the present work a simplified method of assessing the safe load-carrying capacity of flyover piles as well as valuable information about the variables that are interdependent on each other is carried over. The primary focus is on determining the safe load carrying capacity of a pile in the intermediate geo-materials and rock mentioned in sub-cluse 9.1, IRC: 78-2014 includes multiple ways to evaluate the safe load carrying capacity of piles in various types of strata. It is discovered that the formula therein has several variables and restrictions during the safe bearing capacity assessment of a pile in a flyover project. With the help of these restrictions, the formula can be constrained into a more straightforward approach that only requires a few variables to evaluate the safe load-carrying capacity of an end-bearing pile. It is also found that by doing the reverse calculation, the value of (CR+RQD) (rock core + rock quality designation) can be verified at the site. Efforts are also done to find alternate methods for deciding the pile termination point at the site by combining the various aspects between the Unconfined Compressive Strength of rock, rock core recovery (CR), RQD (rock quality designation), shear strength of rock, and Pile Penetration Ratio (PPR).

The design ideology of flyovers, initial load tests on piles, the characteristics of piling rig equipment, and other terms needed to evaluate the safe load carrying capacity of piles are briefly inferred and covered.

Keywords — **Pile, End Bearing, Rock, CR, RQD, UCS, Carrying Capacity, Load Test, PPR, Piling Rig Machine**

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I. INTRODUCTION

The development of flyover projects necessitates a full understanding of the safe load-carrying capacity of end-bearing piles, which is a vital component of the pile foundation system. Estimating the safe load carrying capacity of piles is a complex task that typically involves conducting detailed geotechnical investigations on the ground, performing laboratory tests, analyzing the results in accordance with the guidelines provided by relevant codes, such as the IRC and BIS, etc., and verifying the analysis on the ground through axial, lateral, and uplift load tests.

However, the main objectives taken here are to verify and simplify the equations used to calculate the safe load carrying capacity of end bearing piles (of 1 meter-diameter), with a focus on alternative methods for calculating rock's UCS and establishing the relationship between CR+RQD, UCS of rock and PPR. The ultimate goal is to assist site engineers in quickly and efficiently estimating the safe load-carrying capacity of end-bearing piles with the limited information available at the site.

The methods used in this study are those covered by subclauses 9.1 and 10 of Appendix 5 of IRC: 78-2014, which deal with the capacity of piles in intermediate geo-materials and rock (method 1) and pile termination criteria as a quality control tool in rocks, respectively. Estimating the safe load-carrying capacity of end-bearing piles in flyover projects is made simpler by the reduction of the current approach provided in IRC: 78-2014 to a simplified equation with fewer variables. Additionally, methods for determining the UCS of rock from the PPR data of a particular piling rig machine have been explored. Verifying the safe load-carrying capacity of a pile and finding the interdependency of various variables during assessing the safe load-carrying capacity of a pile, a detailed study of the procedures had been done.

Design aspects to be considered:

To ensure the safety and effectiveness of the construction, careful planning and engineering know-how are needed while designing a flyover. An overview of the steps needed in designing a flyover is provided below:

1. **Traffic Analysis**: To fully understand the volume, speed, and traffic patterns at the site where the flyover is proposed, a detailed traffic analysis must be carried out as the first stage. The necessary capacity and flyover alignment will be determined with the aid of this data.
2. **Alignment and location**: The alignment and location of the flyover are chosen based on the traffic analysis. During this phase, factors including existing road layouts, environmental concerns, and restrictions on the availability of land are taken into account.

One should raise the question during the alignment and location survey of the project:

- Did the flyover project specifically address the local issue of traffic congestion?
- Did the local community and stakeholders participate in the planning process?
- Was the potential impact of the flyover project on the environment evaluated?
- Were the project's general aims and objectives in line with the city or regional development plan?
- Was the project primarily concerned with increasing car traffic, or did it take into account the demands of pedestrians and public transport as well?
- Before choosing the flyover project, were any alternative solutions investigated and assessed?
- Was a thorough cost-benefit analysis performed to determine the project's economic viability?
- Did the development and implementation of the flyover project follow the predetermined schedule and spending plan?
- Did the flyover project's building phase encounter any unexpected difficulties or problems?
- How has the flyover project's completion affected local traffic and congestion?

3. **Structural Design**: Designing the type and arrangement of the bridge components that will make up the flyover's structural framework entails structural design. This includes things like the quantity of piers and abutments, the size of the spans, and the materials that will be employed.
4. **Design of the Foundations**: The stability and integrity of the flyover depend greatly on the design of the foundations. To ascertain the characteristics of the soil and measure its bearing capacity, sub-surface explorations are conducted. Different types of foundations, such as shallow foundations (footings) or deep foundations (piles), may be taken into consideration depending on the soil conditions.
5. **Superstructure Design**: The portion of the flyover that is above the supports is referred to as the superstructure. The decks, girders and any other parts that support the weight of the traffic fall under this category. The ideal size and configuration of the superstructure elements are determined through structural analysis and design calculations.
6. **Traffic Considerations**: When designing a flyover, safety and flow of traffic are also taken into account. This involves figuring out how many and how wide the lanes will be, as well as any other features like barriers, signage, and traffic lights.
7. **Considerations for Construction**: During the design phase, considerations for construction are also made. This takes into account factors like construction staging, temporary supports, and equipment access.
8. **Sustainability and Environmental Impact**: When designing a flyover, it's important to take the environment into account as well. There are steps that can be made to reduce noise pollution, add

green spaces, or lessen any potential detrimental effects on the environment.

9. **Code Compliance**: All applicable building codes, safety regulations, and engineering standards must be followed when designing the flyover. The IRC and BIS regulations are typically followed in India.
10. **Review and approval**: After the design is finished, it is examined for approval by a group of professionals and the necessary authorities. Before final approval is given, any necessary changes or amendments are made.
11. **Construction Documentation**: Based on the approved design, exact construction drawings and specifications are created. The construction team can follow the instructions in these documents to complete the job correctly.
12. **Construction oversight**: Engineers typically conduct construction oversight during the construction phase to make sure that the construction activities are completed in line with the authorised design and specifications. To ensure the quality of the work, they could also carry out routine tests and inspections.
13. **Geotechnical and topographical surveys**: These are important for understanding the site's topography and soil characteristics, which are essential for choosing the flyover's foundation design and alignment.
14. **Drainage Design**: A good drainage plan is necessary to avoid water buildup on the flyover, which could result in structural problems and other damage. In order to maintain proper water runoff, it also comprises the design of gutters, drains, and slope changes.
15. **Safety and accessibility**: When designing a flyover, safety must come first. It also takes into account accessibility for walkers and cyclists with suitable sidewalks or separate paths, guardrails and lights to ensure visibility.
16. **Aesthetics**: Although flyovers are primarily functional, they can also enhance a location's aesthetic attractiveness. Architectural components, landscaping, and integration into the local urban environment may all be taken into account during the design process.
17. **Construction Materials**: Care must be taken in selecting the materials for the flyover structure. Depending on aspects including cost, durability, and structural needs, it could involve the use of concrete, steel, composite materials, or a combination of these.
18. **Maintenance and Durability**: When designing for lifetime, it's important to take the flyover's maintenance and durability needs into account. Corrosion-resistant materials may be chosen, access may be provided for inspection and maintenance, and components may be designed to be simple to repair or replace.
19. **Environmental Impact**: A flyover's environmental impact must also be considered when designing it. This analysis may take into account factors like noise pollution, air pollution, and ecological disruption. The design may include measures to lessen these effects, including noise barriers or green infrastructure.
20. **Future Expansion and Flexibility**: Future expansion or modification requirements should also be taken into account in the design. If necessary, provisions may be made for a larger structure, more lanes, or the incorporation of public transportation networks.
21. **Cost Estimation**: Last but not least, designers must calculate the expenses involved in building, maintaining, and running the flyover. This covers any necessary land acquisition costs, personnel costs, and material expenditures.

In general, the design of a flyover necessitates a multidisciplinary strategy that draws on knowledge in traffic engineering, structural engineering, foundation engineering, and construction management. All parties concerned must work together and coordinate for the design to be implemented successfully.

Background Motivation:

A critical part of pile foundation design is the determination of a safe load-carrying capacity. End-bearing piles, which transfer the imposed loads via the pile tip into the underlying rock or stronger soil layer, play an important role in ensuring the structural stability and integrity of flyover constructions. Traditionally, evaluating the safe load-carrying capacity of end-bearing piles entails a number of processes that take a significant amount of time, effort, and resources.

Rock Core Recovery (RCR): The recovery of undamaged rock samples for analysis and study from the subsurface is referred to as rock sample recovery, or rock core recovery. Depending on the depth and geological characteristics of the location, many approaches can be used to accomplish this.

One popular technique is drilling. Boreholes can be made by drilling rigs, providing access to subterranean rock formations. Different drilling methods, such as rotary drilling, core drilling, or percussion drilling, may be utilised, depending on the goal of the investigation.

Rock quality designation (RQD) is a metric used in civil engineering to characterise the quality of rock material. It is a measurement of a rock mass's general intactness or fracture.

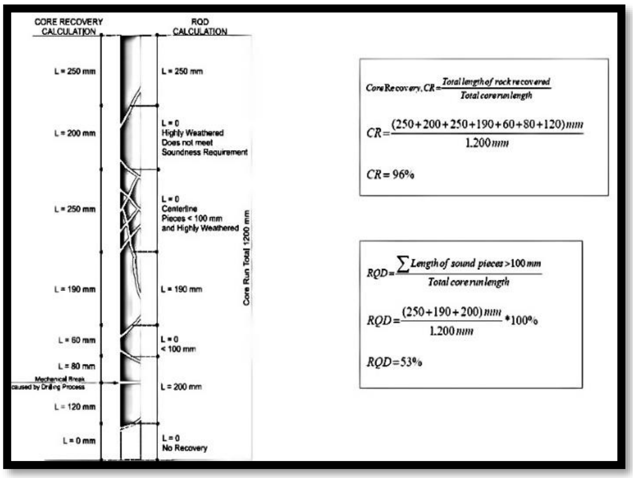


Figure 1: Formulation of CR and RQD

RQD is calculated by analysing drill core samples taken from boreholes. To determine the RQD value, the percentage of intact or sound rock bits over a given length of the sample is determined.A greater value denotes a higher rock quality, and the RQD value ranges from 0 to 100. A rock mass that has an RQD value below 25 is typically severely fractured or extremely weathered. On the other hand, a rock mass with a high quality has an RQD value more than 75. Several civil engineering applications, such as the analysis of rock slope stability, foundation design, tunnelling, and underground mining, utilise RQD. Engineers can use this information to make educated judgements about construction techniques, support systems, and safety precautions by using it to learn more about the strength, stability, and behaviour of the rock mass.

Table 1 – classification of rock of IRC 78:2014, when, UCS of rock is;

>200 MPa	Extremely Strong Rock
100 to 200 MPa	- Very Strong Rock
50 to 100 MPa	- Strong Rock
12.5 to 50 MPa	- Moderately Strong Rock
5 to 12.5 MPa	- Moderately Weak Rock
1.25 to 5 MPa	- Weak Rock
<1.25 MPa	- Very Weak Rock

A quantitative measure called **Rock Mass Rating (RMR)** is used to rate the stability and appropriateness of rock masses for various engineering uses, particularly in underground construction. Z. T. Bieniawski created it in 1976, and afterwards it underwent modifications to add elements like groundwater conditions and discontinuity orientation.

UCS of rock: The ability of a rock to bear compressive stress without the aid of external support or confinement is known as its unconfined compressive strength (UCS). It is a crucial rock engineering characteristic that is frequently applied in geotechnical and civil engineering.

Ultimate load carrying capacity of a end bearing pile: In general, the ultimate carrying capacity of an end-bearing pile is determined by the load-carrying capacity of the pile shaft and the load-carrying capacity of the pile base or tip. The frictional resistance between the pile and the surrounding soil is the main factor that affects the pile shaft's ability to support loads. The diameter, length, type of soil, and characteristics of the soil all have an impact on this frictional resistance. The bearing capacity of the soil at the pile tip determines the load-carrying capacity of the pile base or tip

To ensure that the desired rock layer is reached, the **pile penetration ratio (PPR)** is used throughout the construction process. The energy needs of the rotary piling rig for a particular PPR dictate the precise pile termination point.

Mathematically, PPR stands for the energy in ton-meters required to move a pile bore with 1 m^2 cross-sectional area by 1 cm, as defined by IRC: 78-2014.

Prior to the construction of a flyover, a pile is subjected to an initial load test to ascertain its load-bearing capacity and evaluate its structural integrity. It entails putting a predefined load on the pile typically in increments—and watching to see how it reacts. Generally, three types of tests are performed to assess the safe bearing capacity of a pile: **axial, lateral, and pullout tests.**

IRC: 78-2014 outlines a method for figuring out how much load end-bearing piles can safely support. Several interdependent variables and coefficients in the equation defined by the code must be carefully considered during the estimation process.

The ultimate capacity of a pile socketed into rock, denoted as Q_u, is calculated using the formula below:

$Q_u = R_e + R_{af} = K_{sp}.q_c.d_f.A_b + A_s.C_{us}$ …eq (1)

The permissible/ allowable capacity of pile, represented by Q_{allow}, may be determined using the following equation:

$Q_{allow}=(Re/3) + (Raf/6)$ …eq (2)

To calculate the value of K_{sp}, an empirical coefficient, the equation provides precise values based on CR and RQD. K_{sp} equals 0.3 when $\frac{CR+RQD}{2}$ is 30% and 1.2 when $\frac{CR+RQD}{2}$ is 100%. For middle values, K_{sp} can be linearly interpolated. The average UCS of the rock core beneath the pile base "q_c" is calculated by laboratory testing. It is measured in megapascals (MPa) and represents the compressive strength of the rock material.

The formula for calculating the depth factor, d_f, is: **d_f = 1 + (0.4 x (Socket Length/Socket Diameter)).** Calculating the pile depth factor takes the socket's length and diameter into account.

The area of the pile in contact with the underlying rock, or the area of rock under the pile, is represented by the cross-sectional area of the pile base, A_b.

C_{us}, ultimate shear strength of the rock along socket length, is calculated using the formula:

C_{us} = 0.225 x $\sqrt{qc}$. The ultimate shear strength, however, is limited to the shear capacity of the concrete in the pile. The shear capacity of M35 concrete under constrained conditions is assumed to be 3.0 MPa. For various concrete strengths, this number can be adjusted by a factor of $\sqrt{fck/35}$.

R_e computes the vertical capacity of the pile embedded or socketed in the rock, and R_{af} computes the frictional capacity of the pile socket.

Divide R_e and R_{af} by the code-required safety factors of 3 and 6, respectively, to determine the pile's permitted capacity, or safe capacity.

Use of this formula is subject to the restrictions and guidelines set forth in IRC: 78-2014. These restrictions ensure that the estimation process is accurate and reliable while taking into account the unique characteristics and circumstances of the pile as well as the underlying rock layer.

The Pile Penetration Ratio (PPR) is an important factor in determining pile termination depth. PPR is a measurement used during the piling process to determine the extent of pile penetration into the underlying strata. It aids in the finalization of the pile's termination depth, ensuring that it achieves an acceptable level of penetration to accomplish the specified load-carrying capacity. When piles are built using the Dynamic Compaction Method (DMC) and Piling Rig Machines, IRC: 78-2014 gives a method for calculating PPR. However, given the popularity and widespread usage of piling rig machines in current building practices, the following formula is used to calculate PPR (for piling rig machines):

The formula to calculate PPR is expressed as:

PPR = (2 x π x n x T x t) / (A xP) … eq (3)

Fig. 2: boring work on the test pile

Fig. 3 information screen of Piling Rig Machine

fig. 4 placing of Hydraulic Jack

fig. 5 placing of Test Crown

Fig. 6 PPR data collection – XMCG 220DR

II. LABORATORY INVESTIGATION

TABLE 2 PPR VALUES FOR VARIOUS PILES

Sno	**Pier**	**Pile No**	**Depth (m)**	**UCS at given depth (t/sqm)**	**PPR (tm/sqm/cm)**
1	TP1	-	11.00	3271	2517.46
2	RP10	P1	11.10	4255	4168.91
3	RP10	P2	11.42		3827.38
4	RP10	P3	11.41		3999.17
5	RP10	P4	11.10		3081.34
6	RP10	P5	11.61		4272.35
7	RP5	P1	12.16	4260	3560.47
8	RP5	P2	12.23		3639.64
9	RP5	P3	12.16		3645.13
10	RP5	P4	12.27		3626.35
11	RP5	P5	12.22		3780.13
12	RP7	P6	11.00	4094	3738.31
13	RP7	P2	11.04		3560.47

III. RESULTS

The first objective,simplification of the formula given in IRC 78: 2014, Appendix 5, subclause 9.1, is achieved as specified below:

Let's look at the answers to Ksp and df. Ab in the context of the equations, as well as the final solution to Res, and Raf

SOLUTION TO Ksp: Adding (CR+RQD) into the calculation right away and treating it as a variable that just relies on the information provided in the geotechnical investigation report and doesn't call for any interpolation is the solution to Ksp. As a result, the equation becomes more streamlined and efficient in computing the end-bearing pile's safe load-carrying capacity. However, several constants need to be entertained to consider interpolation for ((CR+RQD)/2). The number (CR+RQD) shows the combined percentage of core recovery (CR) and rock quality designation (RQD), both of which are indications of the strength and integrity of the rock. Now, the equation becomes simpler, and the value may be easily replaced into the formula without further computations. This method simplifies determining the pile's safe load bearing capacity.

Solution to df.Ab including F.O.S OF 3

The solution offered is designed particularly for a 1-meter-diameter pile with a 1-meter-long socket. It takes into account the depth factor (df) and the cross-sectional area of the pile's base (Ab). The depth factor takes into account the length and diameter of the socket, providing an adjustment factor for the computation.

Additional formulae are required to derive the constant values for df.Ab for other pile diameters and socketing lengths. These constants will allow for precise estimations of the safe load bearing capacity of various pile layouts.

It is necessary to highlight that this approach has a factor of safety (FOS) of 3. The safety factor is an important aspect in geotechnical engineering because it ensures that the pile's predicted safe load bearing capacity is much more than the projected applied loads. By including a safety factor, the design becomes more trustworthy and robust, taking into account uncertainties and anticipated variances in actual field circumstances.

final solution to Res including F.O.S of 3

The final solution to Res entails combining the equations relating to Ksp, df. Ab, and other pertinent quantities. By combining these equations, a comprehensive formula for calculating the end bearing pile's safe load carrying capacity is developed.

The solution considers several variables, including (CR+RQD), qc and constants like df and Ab. The value of (CR+RQD) may be calculated on-site using core recovery and rock quality designation analyses. The value of qc, which indicates the average unconfined compressive strength of the rock core beneath the pile's base, can be taken from relating values of PPR and confirmed from Table 3 of IS: 11315 (Part 5) or measured in a laboratory.

The safe load carrying capacity of the end bearing pile (Res) may be calculated by integrating these variables and using the established formula. It is critical to consider the factor of safety of 3 to guarantee that the predicted capacity is much more than the applied loads, hence maintaining the pile foundation's structural integrity and stability.

final solution to Raf including F.O.S OF 6

The top 0.3 m length is neglected during the calculation of the surface area of socketing (the base area should not be calculated); now the value of qc should be the value of either the characteristic strength of concrete or the UCS of rock, whichever is less. However, as per IRC 78:2014, the value of Cus taken as 3 MPa or 300 t/sqm, but in the project, the friction resistance of the socket is taken the least due to safety reasons.

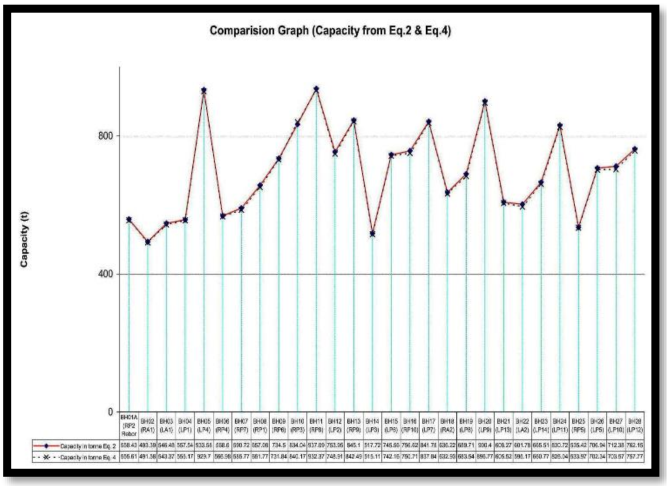
The safe load-carrying capacity of end-bearing piles can be calculated using one of these approaches, which takes into account a number of factors, including the characteristics of the rock, the design of the pile, and the factor of safety. The calculations and solutions proposed make an effort to accelerate the design procedure and boost the dependability of the pile foundation

Final solution is

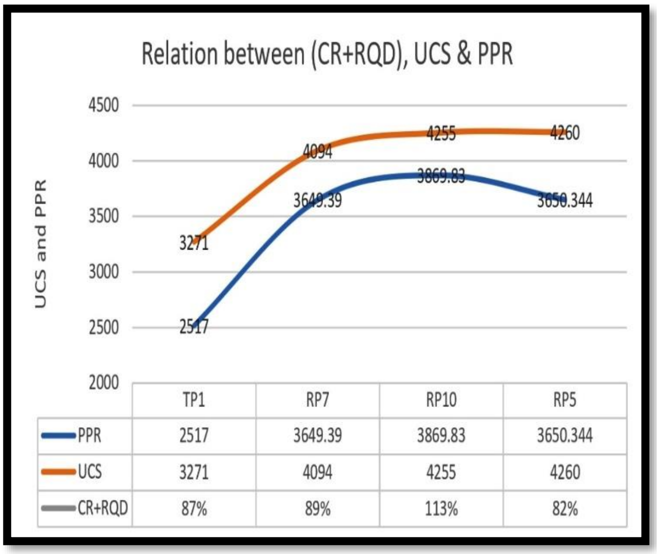
$$Qallow = [\{0.3 + (0.643 \times ((CR+RQD) - 0.6))\} \times 0.314 \times q_c] + [0.825 \times \sqrt{q_c}] \quad \ldots eq\ (4)$$

1. Diameter of pile is 1 m
2. RQD should not be nil
3. CR+RQD ≥ 60% (it should always be in percentage)
4. The value of q_c given in the above formula should always be the smaller value of the characteristic strength of concrete or the UCS of rock.

5. The formula is with factor of safety as per IRC 78:2014



Graph 1 : difference in capacity, calculated from Eq. 1 and Eq. 4



Graph 2 UCS and PPR vs (CR+RQD)

The final equation

q_c=(0.76x(PPR)) +1366.99 …eq (5)

IV CONCLUSIONS

The evaluation of safe load carrying capacity for end bearing piles using the presented formula is a preliminary approach that site engineers can employ. However, it is crucial to remember that there may be some difference in the evaluation compared to the pile's actual safe load carrying capacity of end bearing pile.

The paper's formula provides a simpler technique to evaluating the safe load carrying capacity of end bearing piles. It includes variables like (CR+RQD) and q_c, which indicate the rock's strength and integrity. And the formula is included with all factor of safety and there is no need to solve the equation for factor of safety.

However, it is critical to understand that this method has limits and should be used with caution. The little amount of difference detected in the evaluation when compared to the actual safe load bearing capacity suggests that more refining may be required. This fluctuation might be caused by errors in rock qualities, the correctness of assumptions made, and changes in field circumstances.

To overcome these constraints, it is critical to adhere to the rules and principles outlined in the article. These constraints may include taking into account the precise conditions under which the formula was established, such as a 1-meter-diameter pile with a 1D- long socket. Deviations from these parameters may necessitate further calculations and formula tweaks to assure accurate projections.

Furthermore, site engineers should use professional judgement and consider the project site's particular geotechnical characteristics. Comprehensive site investigations, including geotechnical testing and analysis, can give more accurate data for determining geotechnical safe load carrying capacity. Furthermore, geotechnical engineers' experience and collaboration with other specialists may assist improve the design and assure its durability.

Finally, while the formula described in the study provides a basic way for evaluating the safe load carrying capacity of end bearing piles, it is not without limits and constraints. Because of the minor fluctuation observed and the omission of socket resistance, site engineers should utilize this calculation with caution. To ensure the accuracy and dependability of the safe load bearing capacity evaluation, a complete design strategy that includes detailed site inspections, professional judgement, and coordination with geotechnical specialists is required.

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