International Journal of
Structural Engineering and Analysis
ISSN: 2456-5326
Volume 10, Issue 2, 2024
July-December
DOI (Journal): 10.37628/IJSEA
https://journalspub.com/journal/ijsea/
Research IJSEA

Assessment of Foundation for Pier

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Abstract

The design and assessment of pier foundations are crucial due to the substantial loads they must support. Piers are subjected to significant structural and dynamic loads, requiring a robust foundation system to ensure stability and prevent excessive settlement or failure. A mat foundation is typically selected to distribute these heavy loads over a large area, minimizing pressure on the underlying soil. The bearing capacity is assumed to be based on the presence of a rocky strata, which provides the necessary strength to withstand high load intensities at the foundation base. The depth of the foundation must be carefully determined, accounting for water penetration through the topsoil and the influence of the groundwater table, especially when it is located above the footing. This necessitates a deep foundation to mitigate the risk of soil weakening and ensure long-term stability. In areas where the topsoil is moist and the underlying soil is in a saturated condition, the soil's bearing capacity is considerably reduced. To prevent excessive settlement or foundation failure, it becomes essential to extend the foundation deeper, reaching stable, less permeable soil or rock layers that can support the structure's load more effectively. Additionally, environmental factors, such as fluctuating groundwater levels, moisture penetration, and seasonal changes between wet and dry conditions can adversely affect the foundation's performance over time. Saturated soils pose significant challenges by increasing the likelihood of differential settlement, which can compromise the structural integrity of the pier. Therefore, this paper presents a comprehensive assessment of foundation design for piers, focusing on critical geotechnical factors, the effects of soil moisture and saturation, and strategies to ensure long-term durability and safety of the structure under various environmental conditions. This assessment serves as a guide for designing pier foundations in challenging soil environments where heavy loads and water-related factors are significant considerations.

Keywords: Pier foundation design, soil saturation effects, deep foundations, groundwater influence, structural stability

INTRODUCTION

- Soil is excavated at required depth.
- R.C.C. slab at foundation base is to be provided.
- Appropriate thickness of foundation base slab is provided due to total load acting on foundation base.
- For safety of foundation lateral load at foundation base should be less than lateral strength of soil at foundation base.
- Also the overturning moment produced by lateral load on pier should be less than restoring moment produced by depth of foundation & strength of soil.
- Overturning moment at base of foundation due to lateral load in foundation depth should be less than restoring moment produced by strength of soil at foundation base [1–3].

METHODOLOGY

The approach to assessing the foundations of

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Received Date: October 13, 2024
Accepted Date: October 25, 2024
Published Date: October 30, 2024

Citation: Birendra Kumar Singh. Assessment of Foundation for Pier. International Journal of Structural Engineering and Analysis. 2024; 10(2): 1–8p.

piers encompasses several crucial steps:

1. Site Investigation

- Conduct a thorough geological survey to determine the types of soil present and any existing structures in the area.
- Carry out soil boring to collect samples from various depths for subsequent testing [4].

2. Soil Testing

- Perform laboratory tests on the collected soil samples to evaluate their physical and engineering properties. Key tests include determining grain size distribution, Atterberg limits, shear strength, and compaction characteristics [5].

3. Foundation Design

- Choose the suitable type of foundation (shallow or deep) based on the characteristics of the soil and the anticipated loads.
- Design a mat foundation, calculating the necessary thickness, and reinforcement to ensure effective load distribution and structural integrity.
- Determine the optimal depth for the foundation, considering stable soil layers, and the presence of groundwater [6, 7].

4. Stability Analysis

- Evaluate the soil's capacity to resist lateral loads, ensuring that these loads remain within the limits of the soil's strength.
- Analyze the overturning and restoring moments to confirm that the foundation remains stable against potential overturning or sliding forces.
- Assess the factor of safety to ensure compliance with engineering safety standards [8, 9].

5. Soil Stabilization Techniques

- If soil conditions are found to be inadequate, employ stabilization techniques, such as soil compaction, chemical treatments (like lime or cement), or the use of geosynthetic materials [10].

6. Monitoring and Quality Assurance

- After construction, implement monitoring strategies, including settlement measurements and load testing, to evaluate the foundation's performance under actual conditions.
- This comprehensive methodology facilitates a detailed assessment and design of the pier foundation, ensuring it achieves the necessary stability and load-bearing capacity [11–13].

RESULTS & DISCUSSION

Results & Discussion

The evaluation of the pier foundation focused on key aspects, such as load-bearing capacity, resistance to lateral forces, and overall stability. The findings are summarized below:

1. *Load-bearing capacity:* The foundation's load-bearing capacity was based on a rocky substratum, which provided a solid base capable of supporting significant vertical loads. The reinforced concrete (R.C.C.) slab, designed with adequate thickness, effectively distributed the load across the foundation, reducing the risk of excessive settlement or structural failure. The use of a mat foundation further helped in spreading the load over a wider area, lowering the stress on the soil beneath and enhancing the overall stability of the structure [14].
2. *Lateral load resistance:* The lateral forces acting on the pier were examined relative to the lateral strength of the soil at the foundation level. The analysis confirmed that the soil's resistance was sufficient to handle the applied lateral loads, ensuring the foundation's stability. It was observed that keeping lateral forces within the soil's allowable strength is crucial,

especially in conditions where water infiltration or groundwater fluctuations could weaken the soil [15].

3. *Overturning and restoring moments:* The study of overturning moments resulting from lateral loads revealed that these moments remained below the restoring moments generated by the foundation's depth and the soil's strength. The depth of the foundation provided a sufficient restoring moment to counteract any potential overturning forces, ensuring structural stability. This was particularly significant in areas with moist or saturated soils, where the soil's strength may be compromised, requiring greater attention to foundation depth.
4. *Foundation depth and stability:* Increasing the foundation depth proved to be an effective strategy for improving overall stability, particularly in areas with moist or saturated soils. By extending the foundation to more stable soil or rock layers, the foundation could better resist both vertical and lateral loads. The deeper foundation also contributed to a higher restoring moment, enhancing the structure's resistance to overturning and ensuring long-term stability.
5. *Environmental factors and foundation performance:* Environmental factors, such as groundwater levels and soil moisture, were found to have a significant impact on the foundation's performance. Water infiltration into the upper layers of soil and a high groundwater table can reduce the soil's load-bearing capacity. To mitigate these effects, it was recommended to incorporate proper drainage and waterproofing measures around the foundation to prevent water accumulation and maintain the soil's strength and stability.

DISCUSSION

The results underscore the importance of addressing both geotechnical and environmental considerations in the design of pier foundations. For structures exposed to substantial vertical and lateral forces, a deep foundation with a well-designed mat foundation system is crucial for ensuring long-term stability. The foundation's depth, the thickness of the R.C.C. slab, and the soil's load-bearing capacity were key factors in the foundation's performance.

Lateral load resistance and the relationship between overturning and restoring moments emerged as critical to preventing foundation failure. Proper balance between these forces is essential to avoid potential structural issues, such as sliding or overturning.

Site-specific conditions, including soil moisture content, saturation levels, and groundwater presence, must be carefully considered in the design phase. These factors directly influence the foundation's ability to support loads and maintain its stability over time. By designing foundations with these variables in mind, engineers can create more resilient structures capable of enduring both static and dynamic forces across the structure's lifespan.

- Load on pier = 2000 t.
- Load of pier = 1.2 x 1.2 x 8 x 24 = 27.65 t.
- Total load = 2027.65 t. $= \frac{10}{100} x\ 2027.65$
- 10% wt of foundation = 202.77 t.
- Total wt at foundation base = 2000 + 27.65 + 202.77 = 2230.42 tons.
- This is huge amount of load we require rocky strata at foundation base.
- Bearing capacity of rocky strata 165 t/m^2 $= \frac{2330.42}{165}$.
- Foundation base size required = 13.52 m^2.
- Width at foundation base = 2 m.
- Length of foundation base $\frac{13.52}{2} = 6.76$ meter.
- Huge amount of load hence we provide mat foundation.
- Depth of foundation: $= \frac{2330.42}{13.52}$.
- Load intensity 164 t/m^2.
- Depth of foundation $D_f = \frac{164}{1.5}$ x $0.164 \quad \begin{bmatrix} r & = 1.5\ \text{t/m}^2 \\ \varphi & = 25^o \end{bmatrix}$

Using $D_f = \frac{q}{r} \left[\frac{1-Sin\varphi}{1+Sin\varphi}\right] =$ 18 meter.

- If rainfall = 400 mm (Saturated soil state taken)
- Depth of penetration of water = 3 x 400 = 1.2 m
- Since depth of foundation = 18 m
- Hence the soil will be in moist condition.
- Bearing capacity of soil is lowered by 25%.
- Hence there is a reduction in bearing capacity of the soil.

$$= \frac{25}{100} \text{ x } 165 \Rightarrow 41.25 \text{ t/m2 (Reductionin bearing capacity)}$$

- Hence, we must provide more depth of foundation for this much reduction in bearing capacity of soil.
- Hence more depth of foundation required = $\frac{41.25}{1.5}\ x\ 0.164$ = 4.51 meter (More depth of foundation for moist condition of soil).
- Underlying soil (if ground water table is more than depth of footing).
- Hence underlying soil will be in saturated state bearing capacity of soil is lowered by 50%.
- Hence the bearing capacity of the underlying soil is reduced by = $\frac{50}{100}$ x 165 = 82.50 t/m^2 is the reduction in bearing capacity of the underlying soil.
- For this much reduction in bearing capacity we must provide more depth of foundation and more depth of foundation required = $\frac{82.50}{1.5}\ x\ 0.164$ = 9.02 meters.
- Hence the depth of foundation required (total).

18 + 4.51 + 9.02 ⇒ 31.53 meters, i.e., 32-meter of foundation required for load on pier = 2000 tons acting on pier.

- For huge amount of load acting on pier or on column for tall building mat foundation is used.
- Hence an excavation is done up to a depth of 32 meters and an R.C.C. slab at the foundation base is provided.
- Thickness of foundation base slab required:

$$= \frac{2230.42 \text{ x } 1000 \text{ x } 10}{6.76 \text{ x } 1000 \text{ x } t} = \frac{10}{100} \text{ x } 40 = 4 \text{ (M40 grade concrete)}$$

27040 t = 22304200
t = 825 mm.

- Thickness of foundation base slab required = 825 mm.

Check for Safety of Foundation

- Lateral load at foundation base = 0.217 X 2230.40 = 484 tons.
  $\frac{1 - Sin\varphi}{1 + Sin\varphi} = 0.217, \ (\varphi = 40^{\circ})$
- Lateral strength by strength of soil
  = 165 x 6.76 x 0.825
  = 920 t > 484 tonne.

  Hence O.K.
- Where 165 t/m^2 bearing capacity of soil.
- Length of foundation base = 6.76 m.

International Journal of Structural Engineering and Analysis
Volume 10, Issue 2
ISSN: 2456-5326

- 825 mm = Thickness of foundation base slab.
- The ground water table is above footing hence soil will be in saturated state.
- For soil 16% water absorption reduction in bearing capacity = 50%.
- For rocky strata water absorption = 2%.

Hence for 2% reduction in bearing capacity = $\frac{50}{16 \quad 8}$ x 2 = 6.25 % reduction.

Hence available bearing capacity of the soil at foundation base:

$= \frac{165 - 6.25 \text{ x } 165}{100}$ x 0.164 = 165 – 10.31 = 155 t/m^2.

Hence strength of soil at foundation base = 155 x 6.76 x 0.825= 864 t > 484 t.

Hence O.K.

- Since there is reduction of bearing capacity of soil at foundation base 6.25% of 165 t/m^2 =

$$\frac{6.25}{100} \text{ x } 165 = 10.31 \text{ t/m}^2$$

- Hence more depth of foundation needed for 10.31 t/m^2 reduction

More D_f = required $= \frac{10.31}{1.5}$ x 0.164 $\begin{bmatrix} \text{Where} \\ r = 1.5 \text{ t/m}^2 \\ \varphi = 25^o \end{bmatrix}$ ⇒ 1.127 meter.

Hence the depth of foundation required = 18 + 4.51 + 1.127 = 24 m.

Check for safety of foundation for this much foundation depth

Above G.L. wt of pier: 1.2 x 1.2 x 8 x 24 ⇒ 28 t.

- Load acting on pier = 2000 t.
- Total load = 2028 t.
- Below G.L. 10% wt of foundation taken = $\frac{10}{100}$ x 2028 = 203 t

Lateral load = 0.217 x 203 = 44 t acting at middle ht of $= \frac{24 + 0.825}{2} = 9.90$ Meter

Where 24 m ⇒ Depth of foundation & 825 mm is depth of foundation base hence overturning moment at base of foundation 44 x 9.90 ⇒ 436 tons.

Restoring moment at base of foundation due to bearing capacity of soil = 85 t/m^2.

= 85 x 6.76 x 0.825 x $\frac{0.825}{2}$
⇒ 196 t < 436 tons.

Hence the surrounding soil around base of foundation is stabilized by 2 parts gravel & 8 parts stone particles properly mixed, i.e., stabilized soil is used around base of footing strength =

$$\frac{2 \ x \ 44 \ + \ 8 \ x \ 165}{2}$$

= 704 t/m^2

In saturated state very less, bearing capacity is reduced = $\frac{6.25}{100}$ x 704
= 44 t/m^2.

- Hence 44 t/m^2 is reduction in bearing capacity of soil hence bearing capacity of surrounding stabilized soil = 704-44 ⇒ 660 t/m^2.
- Hence restoring moment near base of foundation due to stabilized soil
  = 660 x 6.76 x 0.825 x $\frac{0.825}{2}$
  = 1518 t > 436 t

Hence O.K.
Top-soil capacity was lowered by 25% due to moist soil:

= $\frac{25}{100\ \ 4} = 5\ \mathrm{t/m^2}$

Reduction in bearing capacity hence topsoil has 15 t/m^2 capacity & bottom soil 155 t/m^2.

Hence the average bearing strength of soil $\frac{15\ +155}{2} = 85\ t/m^2$

Hence restoring moments by strength of soil:

= 85 x 6.76 x $\frac{24}{2}$
= 6895 t-m > 1736 t-m.

Hence O.K.

- Check against overturning moment at base & restoring moment at base:

Lateral load at base 0.217 x 2230.42 = 484 t acting at mid ht of foundation depth slab.

Hence overturning moment at base $\frac{484\ \mathrm{x}\ 0.825}{2} = 200\ \mathrm{t-m}$

- Restoring moment by lateral strength of soil at base:

155 x 6.76 x 0.825 x $\frac{0.825}{2}$ = 357 t-m > 200 t-m.

Hence O.K.

- Since penetration of water in topsoil takes please 3 x 400 [Where 400 mm rainfall & at G.L. soil is in saturated state] = 1.2 meter.
- Check for lateral load due to load of 1.2m depth of pier

  = 1.2 x 6.76 x 2 x 24
  = 23.36 t.
  [Where 1.2 m = Depth of penetration of water.
  6.76 m → length of pier.
  2 m → width of pier below G.L.).

Lateral load = 0.217 x 23.36 = 5.07 tons.

- Strength of soil: Since soil is in moist condition because water will percolate towards bottom soil.

- Bearing capacity of soil at 1.2 m depth:

  Q = 1.8 x 1.2 x 9
  $\phi = 30^o$
- Using $Q = \gamma D \left[\frac{1 + Sin\varphi}{1 - Sin\varphi}\right]^2$.
- Hence bearing capacity of soil at 1.2 m depth = 19.44 t/m^2
  Taking 20 t/m^2
- Since soil is in moist condition bearing capacity is lowered by 25.

  Hence bearing capacity of soil = $\frac{25}{100}$ x 20 = 5 t/m^2.
  (Reduction in bearing capacity of soil)

  Hence the strength of soil at 1.2 m depth = 15 x 1.2 x 6.76 = 122 t > 5.07 t.

  Hence O.K.

CONCLUSIONS

- The analysis of pier foundations highlights the critical importance of ensuring that the underlying soil possesses sufficient strength to bear the load intensity transferred from the structure above. The stability of the foundation relies heavily on the soil's ability to support both vertical and lateral loads without undergoing excessive deformation or failure. In cases where the natural soil does not provide adequate strength, measures must be taken to improve the soil conditions around the foundation.
- To enhance the stability and load-bearing capacity of the foundation, stabilized soil should be provided around the base of the foundation. Stabilization techniques, such as soil compaction, the use of geosynthetics, or the incorporation of additives like cement or lime, can improve the soil's strength and resistance to movement. This stabilized layer not only helps distribute the load more evenly but also provides additional protection against issues like soil erosion, settlement, or water infiltration, which can negatively impact the foundation's performance.
- By improving the surrounding soil, the overall durability and safety of the pier foundation are significantly enhanced. The foundation becomes better equipped to handle both immediate and long-term loads, ensuring the structure remains stable over its lifespan. Therefore, careful consideration of soil strength and stabilization methods is essential for the successful design and construction of pier foundations in various geotechnical conditions.

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APPENDIX

Notation

D_f = Depth of foundation in meter.
γ = Unit wt of soil in t/m^3.
ϕ = Angle of repose in degree.
q = Load intensity in t/m^2.

