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Safety of Foundation of Building

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Abstract

The design of a building's foundation requires careful consideration of the load intensity applied from the structure above. To ensure stability and safety, the foundation depth must be sufficient to support the loads effectively. For residential buildings, where the loads are relatively lower, a foundation base size of 2.5 × 2.5 meters or 3 × 3 meters is typically adequate. In contrast, for structures with significantly higher loads, such as tall buildings or bridge piers, a larger foundation base size of 4× 4 meters is used to distribute the load more evenly and ensure stability. Additionally, lateral forces acting on the column height, especially at the lower section of the column, must be accounted for, as these can significantly impact the foundation's performance. The overturning moment at the ground level, generated by these lateral loads, is calculated and compared against the restoring moment provided by the surrounding soil's strength. This comparison ensures that the foundation can resist tilting or failure due to the applied lateral forces. Furthermore, the soil strength surrounding the foundation base is also assessed to ensure it can adequately support lateral loads, providing a comprehensive approach to foundation safety. Overall, the design process involves evaluating various factors, such as load distribution, soil bearing capacity, and lateral stability, to determine the appropriate foundation depth and base size for different building types. Ensuring these considerations are thoroughly addressed is essential to achieving a structurally sound and durable foundation system.

Keywords: Lateral load acting on bottom column, Overturning moment, Restoring moment, building's foundation

INTRODUCTION

The stability of a building's foundation is crucial for the overall structural integrity, especially when subjected to various forces. One of the primary considerations in foundation design is the effect of lateral loads, which can induce an overturning moment at the base of the structure. This overturning moment, generated by forces such as wind, seismic activity, or uneven loading, has the potential to cause instability if not properly counteracted. To ensure safety, the overturning moment produced by the lateral load acting on the foundation must be thoroughly evaluated and compared to the restoring moment, which is provided by the strength of the surrounding soil. The restoring moment represents the soil's capacity to resist tilting or overturning, thereby stabilizing the foundation [1–4].

In addition to evaluating the overturning moment at the foundation base, it is also essential to consider the lateral load acting below ground level. This includes loads transmitted through the column or other structural elements into the soil. The strength of the soil surrounding the column plays a vital role in resisting these forces and preventing excessive lateral displacement or settlement. Thus, the lateral load acting below ground level must be carefully assessed against the soil's shear strength and bearing capacity to ensure the foundation remains stable under varying conditions [5–7].

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Moreover, it is critical that the overturning moment produced by the lateral load at the base of the column is consistently lower than the restoring moment provided by the soil's strength. If the overturning moment exceeds the restoring capacity, it could lead to foundation failure, compromising the entire structure. Therefore, designing a foundation that can adequately resist overturning involves not only determining the appropriate depth and base size but also considering soil properties, load distribution, and safety factors. By taking these factors into account, the risk of foundation instability can be minimized, ensuring a safe and durable structural system [8, 9].

RESULTS AND DISCUSSION

The safety and stability of a foundation are influenced by various factors, such as load intensity, soil properties, foundation size, and lateral forces. In this analysis, several key aspects were evaluated to determine the adequacy of the foundation design under different loading conditions.

Load Calculation and Foundation Size

The total load acting on the column was calculated to be 120 tons, with an additional weight contribution from the bottom column itself, calculated as:

Weight of bottom column = 0.5m × 0.5m × 4m × 24 kN/m^3 =2.4 tons

his results in a combined weight of:

Total weight = 120 tons + 2.4 tons=122.4 tons

To account for additional safety, 10% of the foundation weight is considered, leading to a final load of:

122.4 tons + 12.24 tons = 134.64 tons

For this load, a foundation base size of 2.5 × 2.5 meters was initially provided, with further analysis required to determine the adequacy of this size.

Foundation Depth Determination

The depth of the foundation was assessed based on the load intensity and soil conditions. The presence of groundwater and the degree of soil saturation significantly impacted the foundation design. For example, with a rainfall of 600 mm, it was assumed that water penetrated 1.8 meters below ground level, causing a portion of the soil to be in a saturated state. Given that 16% of the soil was water-absorbent, approximately 0.29 meters of the soil was considered saturated, while the remaining 1.51 meters was in a moist condition.

Effect of Soil Saturation on Bearing Capacity

The reduction in bearing capacity due to soil saturation was calculated, with a 37.5% decrease in the capacity of the top layer. This was based on the reduction factors of 25% for moist soil and 50% for fully saturated soil. For foundations designed for taller structures or piers with greater depths, the reduction in bearing capacity was compounded, resulting in a total reduction of 75%.

The available bearing capacity after accounting for these reductions was found to be:

25 t/m^2−9.4 t/m^2 = 15.6 t/m^2

Analysis of Overturning and Restoring Moments

The overturning moment at the ground level due to the lateral load on the column was calculated as:

Overturning moment = 0.271 × 122.4 tons = 33.17 t-m

Considering a concrete grade of M30 and a column height of 4 meters, the restoring moment provided by the strength of the soil surrounding the column was:

Restoring moment = 66.34 t-m

Since the restoring moment exceeded the overturning moment, the foundation was deemed stable under these conditions.

Stabilization Measures for Improved Safety

To further enhance the foundation's stability, the soil was stabilized with a mixture of gravel and stone particles in a 1:6 ratio. This stabilization increased the bearing capacity to:

$248\ t/m^2$

The lateral load acting at the foundation base was recalculated as:

0.271 × 134.64 tons = 36.49 tons

The restoring thrust provided by the stabilized soil was:

248 × 2.5 m × 0.18 m = 112 t

This exceeded the lateral load, confirming the effectiveness of the stabilization.

Evaluation of Alternative Foundation Configurations

Different foundation configurations were considered, including increasing the foundation base size to 3 × 3 meters and adjusting the depth to 300 mm. The impact of these changes on the overturning and restoring moments was analyzed. For instance, increasing the base width helped distribute the load over a larger area, further enhancing stability.

Implications of Moisture Content and Soil Conditions

The foundation's performance varied significantly with changes in soil moisture content. For soil with 0.29 meters in a saturated state and 1.51 meters in a moist state, the available bearing capacity was reduced to $12.47\ t/m^2$ after accounting for reductions. These findings underscored the need for thorough soil investigation and moisture control measures.

DISCUSSION

The results indicate that properly accounting for lateral loads, soil saturation, and stabilization measures is crucial for foundation safety. The use of stabilized soil mixtures can significantly improve the bearing capacity and resistance to overturning moments. Additionally, alternative foundation designs, such as increasing base dimensions or using deeper foundations, can provide further safety margins for critical structures.

By considering various factors such as soil condition, load distribution, and stabilization techniques, the study provides a comprehensive approach to foundation safety. These findings emphasize the importance of detailed geotechnical investigations and adaptive foundation design to ensure the long-term stability of buildings and other structures.

- Load acting on column = 120 t
- Weight of bottom column = 0.5 × 0.5 × 4 × 24 = 2.4 t

[c/s of column = 0.5 m × 0.5 m

Length of bottom column = 4 m

Unit weight of concrete = 24 KN/m^3]

Total weight = 120 + 2.4 = 122.40 t

10% weight of foundation = 122.40 + 12.24

$$\left[\frac{10}{100} \, x \, 122.40 = 12.24 \, t\right]$$

134.64 t

- Providing foundation base size = 2.5m × 2.5 m.
- Hence load intensity

$$q = \frac{134.64}{2.5 \; x \; 2.5} = 21.5 \; t/m^2$$

- Hence depth of foundation required

$$D_f = \frac{21.54}{1.80} \; x \; 0.111 = 1.328 \; meter$$

- Using $D_f = \dfrac{q}{\gamma}\left[\dfrac{1-Sin\phi}{1+Sin\phi}\right]^2$
- If rainfall = 600 mm.
- Soil saturated at ground level.
- Penetration depth of water below G.L = 3 x 600 = 1.8 meter.
- Since water absorption of soil 16%

  Hence $\dfrac{16}{100} \, x \, 1.8 = 0.29 \; meter.$
- 0.29 meter depth of soil is in saturated state & remaining depth of soil 1.8-0.29 = 1.51 meter is in moist condition.
- Hence reduction in bearing capacity of soil $\dfrac{25+50}{2}$ 37.5 % taken where 25% reduction in bearing capacity of soil for moist state and 50% reduction in bearing capacity of soil for saturated state.
- *Hence top soil:* is in moist & saturated state hence bearing capacity of soil is reduced by 37.5%.
- For more depth of foundation for tall building or load on pier underlying soil will be in saturated & moist condition due to ground water table above than footing level.
- Hence for more depth of foundation reduction in bearing capacity 37.5% taken for underlying soil.
- Hence total reduction in bearing capacity of soil = (37.5 + 37.5) = 75%.
- For this case (load = 120 t on column for less depth of foundation reduction in bearing capacity = 37.5%.
- Hence reduction in bearing capacity of soil $= \dfrac{37.5}{100} \; x \; 25 = 9.40 \; t/m^2$

  Hence available bearing capacity of soil 25-9.40 = 15.60 t/m^2.
- Overturning moment at G.L. due to lateral load acting on column = 0.271 x 122.40 = 33.17 t

$$Where \left[\frac{1-Sin\phi}{1+Sin\phi}\right] = 0.27$$

$\phi = 35^o$ taken for concrete.

- Hence overturning moment at base $= 33.17\ x \dfrac{4}{2} = 66.34\ t - m$

  [Height of bottom column = 4m]
- Restoring moment given by strength of soil below G.L surrounding the column

$$15.60\ x\ 2.184\ x \frac{2.184}{2} = 37.20\ t - m < 66.34\ \text{t-m}$$

- Since reduction in bearing capacity of soil $= \dfrac{37.5}{100}\ x\ 25 = 9.40\ t/m^2$
- For this reduction we have to provide more depth of foundation.

More D_f required

$$\frac{9.40}{1.8}\ x \left[\frac{1 - Sin25^o}{1 + Sin25^o}\right]^2 = 0.856\ meter$$

Total depth of foundation = 1.328 + 0.856 = 2.184 meter.

- We have to provide stabilized soil (1:6) (Gravel 1 stone particles) strength

$$= \frac{44\ x\ 6\ x\ 165}{2} = 397\ t/m^2$$

- Since reduction in bearing capacity 37.5%.

  Hence reduction in bearing capacity $= \dfrac{37.5}{100}\ x\ 397 = 149\ t/m^2$
- Available bearing capacity of soil = 397-149 = 248 t/m^2.
- Hence restoring moment provided by stabilized soil

$$248\ x\ 2.184\ x \frac{2.184}{2} = 591\ t - m > 66.34\ t - m$$

  Hence O.K.
- Hence stabilized soil 1:6 [Gravel 1 stone particles provided below the G.L]
- Since 134.64 t load acting on foundation base hence lateral load at foundation base = 0.271 x 134.64 $\Rightarrow$ 36.49 t
- Restoring thrust given by strength of soil around base of foundation

$$248 \times 2.50 \times 0.18 = 112\ \text{t} > 36.49\ \text{t}$$

  Hence O.K.
- Where 2.5 m width of foundation & 0.180 m is depth of foundation base

  Since $\dfrac{134.64\ x\ 1000\ x\ 10}{2.5\ x\ 1000\ x\ t} = \dfrac{10}{100}\ x\ 30$

  t = 180 mm

  [M30 grade concrete at foundation base]

  Tensile strength of M30 $= \dfrac{10}{100}\ x\ 30$

- Overturning moment at base due to lateral load of column at foundation base

$$36.48\ x\ \frac{0.18}{2} \Rightarrow 3.284\ t-m$$

- Restoring moment by stabilized soil around base of foundation

$$248\ x\ 2.5\ x\ 0.18\ x\ \frac{0.18}{2}$$

$\Rightarrow$ 10.04 t-m > 3.284 t-m

Hence O.K.

- Load at G.L. = 122.40 t + 10% of weight of foundation

$$122.40 + \frac{10}{100}\ x\ 122.40$$

$\Rightarrow$ 122.40 + 12.24

$\Rightarrow$ 134.48 t

- Lateral load below G.L.

$$= 0.271\ \text{x}\ 134.48 \Rightarrow 36.44\ \text{t acting at}\ \frac{2.184}{2}\ m$$

- Overturning moment at base

$$= 36.44\ x\ \frac{2.184}{2} \Rightarrow 39.79\ t-m$$

- Restoring moment by stabilized soil surrounding the foundation base

$$248\ x\ 2.5\ x\ \frac{0.18}{2}\ x\ 0.18 = 10.04\ t-m < 39.79\ t-m$$

Not O.K.

- 10% weight of foundation = 12.44 t
- Overturning moment at foundation base $= 12.44\ x\ \frac{2.184}{2} \Rightarrow 13.58\ t-m$

Restoring moment at foundation base

$$248\ x\ 2.5\ x\ \frac{0.18}{2}\ x\ 0.18 = 10.04\ t-m < 13.58\ t-m$$

Not O.K.

- Hence soil is stabilized by 1:8 (Gravel 1 stone particles)

$$= \frac{44 + 8\ x\ 165}{2} = 682\ t/m^2$$

- Bearing capacity of soil is reduced by 37.5 due to penetration of water $\frac{37.5}{100}\ x\ 682 = 256\ t/m^2$

(Reduction in bearing capacity)

- Hence available bearing capacity = 682 – 256 ⇒ 4.26 t/m^2
- Hence restoring moment

$$426 \times 2.5 \times 0.18 \times \frac{0.18}{2}$$

= 17.253 > 13.58 t-m

Hence O.K.

Also

$$426 \times 3 \times 0.30 \times \frac{0.30}{2}$$

= 57.51 t-m > 39.79 t-m

Hence O.K.

- Hence soil is stabilized by 1:8 (Gravel 1 stone particles), 3m = width of foundation & 0.30 m depth of foundation base taken.
- 0.29 m depth of soil is in saturated state & 1.51 meter depth of soil in moist condition.
- Bearing capacity of soil for 0.29 m depth of soil

$$q = 1.8\ x\ 0.29\ x\ \left[\frac{1+Sin15^o}{1-Sin15^o}\right]^2$$

= 1.51 t/m^2

$$Where\ q = \gamma D\ \left[\frac{1+Sin\phi}{1-Sin\phi}\right]^2\ \ taken$$

Since it is in saturated state

Hence $\frac{50}{100}\ x\ 1.51 = 0.754\ t/m^2$

(Reduction in bearing capacity)

Available bearing capacity of soil = 1.51-0.754 ⇒ 0.756 t/m^2

Similarly for 1.51 m depth of soil

$$q = 1.8\ x\ 1.51\ x\ \left[\frac{1+Sin25^o}{1-Sin25^o}\right]^2$$

= 16.53 t/m^2

bearing capacity is lowered by 25%

$$\frac{25}{100}\ x\ 16.53 = 4.06\ t/m^2$$

Available bearing capacity of soil 16.53–4.06 = 12.47 t/m^2

Hence available bearing capacity of top soil

$$\frac{0.756\ x\ 12.47}{2} = 6.613\ t/m^2$$

Total load at G.L. = 122.40 t + weight of depth of column of (1.8 m depth = 0.29 + 1.51 m)

= 122.40 + 0.5 × 0.5 × 1.8 × 24

[Where c/s area of column = 0.5 m × 0.5 & 1.8 m depth & 24 KN/m^3

= Unit weight of concrete)

= 124.40 + 1.08

= 125.48 t

Another Way

2.184 meter depth of foundation → 10% weight of foundation

For 1.8 m → 8.24 %

(0.29 × 1.8m)

Hence load below G.L. of column

$$\frac{8.24}{100}\, x\, 122.40 = 10.09\, t$$

Hence total load below G.L. = 122.40 + 10.09 = 132.49 t

- Hence lateral load below G.L. (Total)

  = 0.271 × 132.49

  = 35.905 t

  Strength of stabilized soil

  = 248 × 0.5 × 1.8 ⇒ 223 t > 35.905 t

  Hence O.K.

  Dry soil below 1.8 m depth = 2.184-1.8

  = 0.384 meter

  For 2.184 m depth of foundation 10% weight of foundation.

  For 0.384 m depth ⇒ 1.758 %.

  Hence $\frac{1.758}{100}\, x\, 120 + 2.4 + 10.09 = 2.33\, t$

  Hence total load = 120 + 2.4 + 10.09 + 2.33 ⇒ 134.82 t

  Lateral load 0.271 x 134.82 ⇒ 36.54 t acting at $\frac{2.184}{2}$

- Overturning moment $= 36.54\, x\, \frac{2.184}{2} = 39.90\, t - m$ at foundation base.

  Restoring moment at foundation base

  $$= 248\, x\, 3\, x\, 0.3\, x\, \frac{0.3}{2} = 28\, t - m < 39.90\, t - m$$

  Hence soil is stabilized by 1:9 [1 part gravel & 9 parts stone particles]

Hence strength

$$\frac{44\ x\ 9\ x\ 165}{2} = 765\ t/m^2$$

Since top soil is in moist & saturated condition hence bearing capacity is lowered by 37.5%.

Hence reduction in bearing capacity $\frac{37.5}{100}\ x\ 765 = 287\ t/m^2$

[Reduction in bearing capacity]

Available bearing capacity of stabilized soil = 765-287 = 478 t/m^2

Hence restoring moment given by stabilized soil

$$= 478\ x\ 3\ x\ 0.3\ x\frac{0.3}{2} \Rightarrow 64.53\ t-m > 39.90\ t-m$$

Hence O.K.

CONCLUSIONS

- In conclusion, the use of stabilized soil with a 1:9 ratio, consisting of 1 part gravel and 9 parts stone particles, proved to be an effective approach for enhancing the stability and safety of the foundation. This mixture significantly improved the soil's bearing capacity and resistance to deformation, providing a more reliable base for structural loads. The inclusion of gravel contributed to better drainage properties, which is essential for minimizing the impact of soil saturation and moisture-related issues. The stone particles in the mixture added structural integrity, reducing the likelihood of settlement and providing a stable platform to support the foundation.
- The selected foundation base size of 3 meters by 3 meters allowed for a broader distribution of the applied loads, thereby reducing the pressure on the soil beneath the foundation. This larger base size was particularly beneficial for structures subjected to heavier loads, as it helped to prevent excessive settlement and increased the overall safety margin. By spreading the weight across a wider area, the foundation was able to maintain its stability even under varying soil conditions, such as moisture fluctuations or lateral loads from wind and seismic activity.
- The depth of the foundation base, set at 300 millimeters, was carefully chosen to ensure that the foundation was anchored in a stable and supportive soil layer. This depth provided adequate load transfer and contributed to the foundation's resistance to both vertical and horizontal forces. Additionally, the 300 mm depth facilitated the integration of the stabilized soil mixture, ensuring a uniform and solid base that effectively mitigated the risk of soil movement or settlement over time.
- Overall, the combination of a stabilized soil mixture, an appropriately sized foundation base, and a suitable depth created a robust and durable foundation system. This approach not only met the safety standards for various building applications but also provided flexibility to adapt to different soil conditions and load requirements. The results underscore the importance of selecting the right stabilization techniques and foundation dimensions to ensure the long-term stability and performance of building structures. By considering factors such as soil properties, load intensity, and environmental influences, the foundation design achieved a balance between safety, efficiency, and cost-effectiveness.

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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 = Bearing capacity in soil in t/m^2.