STM JOURNALS

Journal of
Industrial Safety Engineering

ISSN: 2395-6674
Volume 11, Issue 3, 2024
September–December
DOI (Journal): 10.37591/JoISE

https://journals.stmjournals.com/joise

Research JoISE

The Importance of Safety Engineering in the Design and Assessment of Foundations

Birendra Kumar Singh[1,*]

Abstract

In safety engineering, ensuring the stability of structures under lateral loads is a critical aspect of foundation design. Lateral forces, such as wind, seismic activity, or other environmental pressures, exert overturning moments on columns, which must be carefully managed to prevent structural failure. To maintain stability, the overturning moment at the foundation base, generated by these lateral loads, must always be less than the restoring moment produced by the soil's bearing capacity at the foundation depth. This restoring moment is a stabilizing force that counters the tendency of the structure to topple, ensuring that the foundation remains secure and upright. Additionally, the lateral load acting on the foundation must not exceed the shear strength of the surrounding soil. If the lateral forces surpass the soil's capacity to resist them, it can lead to sliding or soil failure, compromising the foundation's stability. The strength of the soil is a crucial factor in determining the maximum lateral load the foundation can safely support. Ensuring that the lateral load is within the safe limits of the soil's strength prevents displacement and protects the integrity of the structure. Moreover, the overturning moment generated within the foundation depth, due to lateral loads on the column, must also be less than the restoring moment provided by the soil. This balance is essential in preventing rotational instability or toppling. Proper evaluation of both the lateral forces and the soil properties, such as bearing capacity and shear strength, is necessary to achieve this balance.

Keywords: Foundation base size, depth of foundation base, bearing capacity of soil

INTRODUCTION

Ensure the stability and safety of foundations under various loading conditions is a critical design consideration, particularly when lateral loads are present. These loads, which may result from vertical loads acting on the column, environmental forces such as wind or seismic activity, or operational conditions, generate significant stresses at the base of the structure. Proper assessment of the lateral load acting on the bottom of the column is crucial for predicting potential structural behavior under these conditions [1].

One of the key parameters to evaluate is the overturning moment at the base of the foundation. This moment is induced by the lateral load acting on the column and can lead to potential instability or failure if not properly counteracted. To prevent such failure, it is essential to calculate the restoring moment, which is produced by the bearing capacity of the soil at the foundation depth. The soil's resistance provides the necessary stabilizing force to counterbalance the overturning moment, and for the foundation to remain stable, the restoring moment must always exceed the overturning moment [2].

Additionally, the lateral load acting at the foundation base must be considered. This load must remain within the strength limits of the soil

*Author for Correspondence
Birendra Kumar Singh
E-mail: birendrasingh.civil@yahoo.co.in

[1]Professor, Civil Engineering Department, Birla Institute of Technology, Mesra, Ranchi, Jharkhand, India

Received Date: September 25, 2024
Accepted Date: October 10, 2024
Published Date: October 14, 2024

Citation: Birendra Kumar Singh. The Importance of Safety Engineering in the Design and Assessment of Foundations. Journal of Industrial Safety Engineering. 2024; 11(3): 24–29p.

surrounding the foundation. The strength of the soil is determined by factors such as the foundation base size, its thickness, and the soil's properties, and it must be able to resist any lateral forces without allowing excessive displacement or failure. If the lateral load exceeds the soil's strength, it can lead to sliding, settlement, or collapse, which compromises the safety of the foundation [3].

Furthermore, the overturning moment produced by the lateral load acting on the column, particularly for the depth of the foundation, must be less than the restoring moment provided by the soil's bearing capacity, the foundation base size, and its thickness. Maintaining this balance is essential for preventing rotational instability and ensuring the long-term stability and safety of the structure [4].

RESULTS AND DISCUSSION

Results and Discussion: Structural Stability Analysis of Column and Foundation

Load on Column and Foundation Base

The column carries a vertical load of 120 tons. The total load at the foundation base is determined by adding 10% of the foundation's own weight to the column load, resulting in a total of 132 tons. The foundation base has a thickness of 220 mm, which is important for calculating its stability against various forces [5].

Overturning Moment and Restoring Moment

In structural design, the overturning moment is caused by lateral forces, such as wind or seismic activity, acting on the structure. This moment must be counteracted by the restoring moment provided by the soil's bearing capacity to maintain stability.

The lateral load acting on the column is calculated to be 26 tons, and it generates an overturning moment at the base. This moment must be compared with the restoring moment provided by the soil. The restoring moment is determined based on the soil's bearing capacity, the depth of the foundation, and the width of the column. For this case, the soil provides a restoring moment of 56 ton-meters, which is greater than the overturning moment of 52 ton-meters. Since the restoring moment exceeds the overturning moment, the design is considered safe from overturning [6].

Lateral Load at Foundation Base

The lateral load acting at the foundation base is evaluated to be 29 tons, taking into account the increased load due to the weight of the foundation itself. To ensure the foundation remains stable, the strength of the soil at the base is calculated. The soil strength, determined by its bearing capacity and the dimensions of the foundation, is 36 tons, which is higher than the lateral load. This confirms that the foundation is safe and will not fail due to lateral forces [7].

Additional Stability Considerations

The weight of the column below the ground, considering the foundation depth and the column's cross-sectional area, adds further lateral load. This additional load creates a small overturning moment. However, the soil's bearing capacity at this level provides adequate restoring moment, ensuring stability (Tables 1 and 2) [8].

- Load on column = 120 t
- Load at foundation base = 120 + 10% wt of foundation.
  = 132 t

Table 1. Data for load with b × d and D_f.

S.N.	Load on column in tone (W)	Foundation base size in m^2 (b × d)	Depth of foundation in meter (D_f)
1.	120	3 M × 3 M	2
2.	90	2.5 M × 2.5 M	2

S.N.	Foundation base thickness in mm (t)
(1)	300
(2)	200

Table 2. Data for $\frac{W}{W_{max}}$, $\frac{b\times d}{(b\times d)_{max}}$, $\frac{D_f}{D_{f_{max}}}$ and $\frac{t}{t_{max}}$.

S.N.	$\frac{W}{W_{max}}$	$\frac{b\times d}{(b\times d)_{max}}$	$\frac{D_f}{D_{f_{max}}}$	$\frac{t}{t_{max}}$
1.	1.000	1.000	1.000	1.000
2.	0.750	0.694	1.000	0.833
Average	0.875	0.847	1.000	0.917

- Thickness of foundation base

  $\frac{1320000}{2000\times t} = \frac{10}{100} \times 30$ [M30 grade concrete]

  t = 220 mm.
- Check for overturning moment at base and restoring moment given by soil strength.
- Lateral load acting on column = 0.217×120

  Where $= \frac{1-Sin\phi}{1+Sin\phi} = 0.217 \qquad \phi = 40°$

  = 26 t
- This lateral load acting at $\frac{4}{2}$ $[Column\ ht = 4m]$
- Overturning moment at base = 26×2 = 52 t-m
- Restoring moment at base given by strength of soil

  2.5×0.6×30×$\frac{2.5}{2}$ [2.5 m = Depth of foundation

  0.6 m ⇒ width of column
  30 t/m^2 ⇒ Bearing capacity of soil]
  = 56 t- m > 52 t-m
  Hence O.K.
- Taking foundation base width = 3 m
  Bearing capacity of soil = 30 t/m^2
  Depth of foundation = 2.5 m.
- Lateral load at foundation base 0.217×132 ⇒29 t
- Strength of soil in foundation base 30×3×0.40 ⇒ 36 t > 29 t
  Hence O.K.
- 0.40 m is thickness of foundation base.
- Weight of column below G.L [foundation depth]

  2.5×0.6×0.6×24 = 2.16 t

  [Where D_f = 2.5 m
  C/s area of column = 0.6 m × 0.6 m
  Unit weight of concrete = 24 KN/m^3]
  Lateral load
  0.217×2.16 = 0.469 t acting at middle of depth 2.5 m + 0.4 m i.e.

  $\frac{2.5+0.4}{2} \Rightarrow 1.45$ meter

  Hence overturning moment at base = 0.469×1.45 ⇒ 0.680 t-m

Restoring moment at base given by soil

$$3 \times 30 \times 0.4 \times \frac{0.4}{2} \Rightarrow 7.2t - m > 0.680t - m$$

Hence O.K.
Where 30 t/m^2 = Bearing capacity of soil
= 0.40 m depth of foundation base = 3m = width of foundation base.

Corresponding to average value of $\frac{t}{t_{max}} = 0.917$

$\approx 1.000,\ \frac{W}{W_{max}} = 1.000,\ \frac{b\times d}{(b\times d)_{max}} = 1.000,\ \frac{D_f}{D_{f_{max}}} = 1.000$

Average value of $\frac{W}{W_{max}} = 0.875,\ \frac{b\times d}{(b\times d)_{max}} = 0.847,\ \frac{D_f}{D_{f_{max}}} = 1.000$

Hence power of $\frac{W}{W_{max}} = \frac{0.875}{1.000},\ \frac{b\times d}{(b\times d)_{max}} = \frac{0.847}{1.000} = 0.847,\ \frac{D_f}{D_{f_{max}}} = 1.000$

Hence $\frac{t}{t_{max}} = x\left[\frac{W}{W_{max}}\right]^{0.875}\left[\frac{b\times d}{(b\times d)_{max}}\right]^{0.847}\left[\frac{D_f}{D_{f_{max}}}\right]^{1.000}$

Average value of $\frac{t}{t_{max}} = 0.917$

$\frac{W}{W_{max}} = 0.875,\ \frac{b\times d}{(b\times d)_{max}} = 0.847$
D_f = 1.00
D_{fmax}
Hence model is 0.917 = x $[0.875]^{0.876}$ $[0.847]^{0.847}$
Hence x = 1.186

Hence model is $\frac{t}{t_{max}} = 1.186\left[\frac{W}{W_{max}}\right]^{0.875}\left[\frac{b\times d}{(b\times d)_{max}}\right]^{0.847}\left[\frac{D_f}{D_{f_{max}}}\right]$

- Equation (1) is model for thickness of foundation with width, load on column and depth of foundation.
- *Prediction:* load on column = 150 t

  $\frac{t}{t_{max}} = 1.186\left[\frac{150}{120}\right]^{0.875}\left[\frac{2}{3}\right]^{0.847}\left[\frac{3}{2}\right]$

  For 150 t load on column b x d = 2 m × 2 m and D_f = 3 m
  t = 462 mm
- If load on column is increased by 20% i.e. 124 t
  For that t = 366 mm

Other parameters are taken as constant.

- Due to 20% increase in load on column thickness of foundation base increased by 22% similarly.
- Due to 20% increase in base size thickness of foundation base increased by 38%.
- Due to 20% increase in depth of foundation base thickness is increased by 42%.
- Hence depth of foundation is dominant parameter for thickness of foundation base.
- Increase in foundation base related to more load also increase in foundation depth related to more load we need more thickness of foundation base.

METHODOLOGY

The methodology for evaluating the structural stability of a column and foundation under vertical and lateral loading conditions involves several key steps. First, the vertical load on the column is calculated, which is combined with an additional 10% to account for the weight of the foundation, giving the total load at the foundation base. Next, the lateral load acting on the column is determined by applying a factor based on environmental conditions, such as wind or seismic forces, to the vertical load. This lateral load is crucial as it leads to the development of an overturning moment, which is calculated by multiplying the lateral load by the height at which it acts. The overturning moment is a critical factor that could potentially destabilize the foundation if not properly resisted. To counteract this, the restoring moment generated by the soil beneath the foundation is calculated. The soil's bearing capacity, combined with the depth and width of the foundation, provides the restoring moment, which must exceed the overturning moment to ensure stability. In addition to the overturning moment, the lateral load at the foundation base is evaluated and compared against the shear strength of the surrounding soil. The soil strength is calculated using the bearing capacity and the foundation's dimensions to confirm that the lateral load does not exceed what the soil can safely support. Furthermore, the weight of the column below ground level is factored into the analysis to account for additional lateral forces, with the restoring moment from the soil at deeper levels also considered. Finally, the foundation's stability is verified by ensuring that the restoring moment surpasses the overturning moment and that the lateral loads remain within the soil's strength capacity. This comprehensive process ensures that the foundation can safely resist the applied forces and moments, providing structural integrity in industrial applications [8–10].

CONCLUSIONS

- The depth of a foundation is a key factor in determining the necessary thickness of the foundation base. As the foundation depth increases, the foundation encounters higher vertical loads and more substantial lateral forces from soil pressure. To safely transfer these loads and resist failure, the foundation base must be designed with adequate thickness. A deeper foundation interacts with a larger volume of soil, distributing loads over a broader area, which helps in reducing stress concentrations. However, the greater depth also introduces additional earth pressure and potential lateral forces, which require a thicker base to counteract these forces effectively.
- The increased thickness of the foundation base allows it to support bending moments and shear forces that arise at deeper levels. It also helps maintain the stability of the structure by preventing excessive settlement or deformation under load. Therefore, as foundation depth increases, the base must be proportionally thicker to ensure it can handle the combined vertical and lateral loads without compromising structural integrity.
- In conclusion, the depth of the foundation is a primary factor in determining the thickness of the foundation base. A deeper foundation requires a thicker base to manage the increased loads, resist bending, and ensure long-term stability. This relationship between depth and base thickness is critical in the structural design process, ensuring the foundation can safely support the building above.

REFERENCES

1. Fleming WGK, Weltman AJ, Randolph MF, Elson WK. *Piling Engineering*. 2nd ed. Taylor & Francis; 1994.
2. Budhu M. *Foundations and Earth Retaining Structures: A Guide to Design and Analysis*. 2nd ed. Wiley; 2008.
3. Smith IJ. *Smith's Elements of Soil Mechanics*. 9th ed. Wiley-Blackwell; 2013.
4. Braja DM. *Advanced Soil Mechanics*. 4th ed. CRC Press; 2013.
5. Bureau of Indian Standards (BIS). *IS 456: Code of Practice for Plain and Reinforced Concrete*. BIS; 2000.
6. Bureau of Indian Standards (BIS). *IS 1904: Code of Practice for Design and Construction of Foundations in Soils: General Requirements*. BIS; 1986.
7. Reese LC, Wright SG, Wang ST, Arrellaga JA. *Analysis and Design of Shallow and Deep Foundations*. 1st ed. Wiley; 2006.
8. Brinkgreve RBJ, Kumarswamy S, Swolfs WM. *Plaxis 3D Reference Manual: Geotechnical Safety and Design*. 2017.

9. Reddy JN. *Mechanics of Laminated Composite Plates and Shells: Theory and Analysis*. 2nd ed. CRC Press; 2004.
10. Craig RF. *Structural Safety and Performance of Foundations*. 3rd ed. CRC Press; 1997.

APPENDIX

Notation

W	=	Load on column in tonne.
b x d	=	Foundation base size in m^2.
D_f	=	Foundation depth in meter.
t	=	Thickness of foundation base in mm.

