Limit State Design of Shallow Footings as Per Eurocode 7 and its Comparison with IS Code WSM

Aditi K. Sheth[1[0000-0003-2517-4456]] and K. N. Sheth[2[0000-0001-8016-6665]]

[1] Assistant Professor, Department of Civil Engineering, Dharmsinh Desai University, Nadiad
[2] Professor, Department of Civil Engineering, Dharmsinh Desai University, Nadiad
aks.cl@ddu.ac.in

Abstract. Structural Design Practice has transformed from conventional Working Stress Method to Limit State Method - Load and Resistance Factor Design (ACI) or Partial Safety Factor approach (IS Code). Geotechnical Design Philosophy is in the transformation stage to implement Load and Resistance Factor Design (LRFD). Eurocode-7 accommodates three design approaches (DAs) that allow partial factors to be introduced at the beginning of the calculations (strength partial factors) or at the end of the calculations (resistance partial factors), or some intermediate combinations thereof. IS 6403 provides guideline to calculate ultimate bearing capacity for shallow foundations. It gives bearing capacity factors and other factors viz. inclination factors, depth factors, shape factors etc. and accounts for the effect of water table. To calculate allowable bearing pressure a Factor of Safety 2.50 is recommended separately by IS 1080. Eurocode 7 provides guideline for proportioning shallow foundations using partial safety factors for Action, Material Parameters and Resistance. The Action includes Dead Loads as well as Imposed Loads. Material Parameters includes shear parameters ‘c’ and ‘φ’ in drained and/or undrained state. The Resistance Factors are assigned based on the design methods used. For shallow foundations three design approaches are considered for which partial safety factors are given. Parametric study is carried out to compare the ratio of capacity obtained from IS Code WSM and EC7 LSM for different soil type (c-soil, phi - soil and c-phi soil) keeping other parameters constant.

Keywords: Limit State Method, Partial Safety Factor, Shallow Foundation, bearing capacity.

1 Introduction

Engineering designs are established to satisfy the requirements of safety, serviceability and economy. Guidelines for various design philosophies, and values of the applicable factor of safety are put together in design codes. Codes provide guidelines to to help engineers in making appropriate decisions while developing a safe and economical design in accordance with accepted criteria. Structural Design Philosophy and its implementation to Standard Codes has transformed from Working Stress Method to Limit State Method - Load and Resistance Factor Design (ACI) or Partial Safety Factor approach (IS Code).

Geotechnical Design follows Working Stress Method (WSM) which has a single margin of safety. A single factor of safety is used, which encompasses all uncertainty associated with the design process – in working loads, soil parameters, site variability and calculation methods. However, no factor of safety can be made large enough to account for gross human error. Thus, it is essential that the geotechnical engineer uses his/her judgement and experience. In fact, the factors of safety were developed as a result of experience, trial and error, and insight gained from previous designs. WSM does not encourage engineer to think about and differentiate between the behaviour of the structure under ultimate loading and serviceability conditions

Mainly due to initiative through Eurocode-7, Canadian Code, the philosophy of design for Geotechnical Problems is in the transformation stage to implement Load and Resistance Factor Design (LRFD).

2 Formulation for Shallow Foundation as per EC

EC7 [6] introduces design approaches which are different by application of partial factors. According to EN 1997-1 the partial factors are applied to: a) loading actions or their effect, b) properties of foundation soil M, or to resistances R or both. The partial factors differ by the assumed design approach and by the type of geotechnical task (support structures, pile foundation, etc.).

a) Design approach 1 – Verification is performed for two sets of coefficients (Combination 1 and Combination 2) used in two separate analyses.

- For combination 1, the partial factors are applied to loading actions only, the remaining coefficients are equal to 1.0.
- For combination 2 the partial factors are applied to material parameters (material parameters of soil) and to variable loading actions, the remaining coefficients are equal to 1.0.

b) Design approach 2 – Applies partial factors to loading actions and material resistance (bearing capacity)

c) Design approach 3 – Applies partial factors to loading actions and at the same type to material (material parameters of soil)

The sets of partial factors are summarized in Tables 1, 2 and 3 are given in EC7 for different Design-Approaches.

Table 1. Partial Factors on actions (γ_F)or the effects of actions (γ_E)

Actions		Symbol	Set	
			A1	A2
Permanent	Unfavorable		1.35	1.0
	Favorable	[illegible]	1.0	1.0
Variable	Unfavorable	[illegible]	1.5	1.3
	Favorable	[illegible]	0	0

Table 2. Partial Resistance Factors for Spread Foundations (γ_R)

Resistance	Symbol	Set		
		R1	R2	R3
Bearing	[illegible]	1.0	1.4	1.0
Sliding	[illegible]	1.0	1.1	1.0

Table 3. Partial Factors for Soil Parameters (γ_M)

Soil Parameter	Symbol	Value	
		M1	M2
Shearing Resistance	[illegible]	1.0	1.25
Effective Cohesion	[illegible]	1.0	1.25
Undrained Strength	[illegible]	1.0	1.4
Unconfined Strength	[illegible]	1.0	1.4
Weight density	[illegible]	1.0	1.0

[1] This factor is applied to tan Ø'

The check on the bearing resistance of a spread foundation is given by:

$$V_d \leq R_d$$

where,

V_d is the ultimate limit state design load normal to the foundation base including the weight of the foundation and of any backfill material. In drained conditions water pressure shall generally be included as actions in calculating V_d

R_d is the design bearing resistance of the foundation against normal loads, taking into account the effect of any inclined or eccentric load. R_d shall be calculated from design values of the relevant parameters after the application of the partial factors of the material properties to it.

3 Comparative Study

Inputs Parameters for Safe Bearing Capacity calculation as per IS Code includes:

Type of Shear Failure	Depth of Footing
Cohesion	Ground Water Table conditions
Angle of Internal Friction	Unit Weight of Soil above/below GWT
Type of Footing	Factor of Safety
Footing Dimensions	

Additional Input Parameters required as per Euro Code includes Imposed Permanent Load, Imposed Variable Load and Horizontal Load.

The safe bearing capacity of shallow foundation as per IS Code and EC7 are calculated for various range of soil parameters for a square footing of width 2.0 m resting at the depth of 2.0 m on a soil with bulk density 18 kN/m^3 as follows:

- Cohesionless soil with ϕ varying from 21 to 45 degrees.
- Cohesive soil with c varying from 50 kN/m^2 to 150 kN/m^2.
- C-φ soil with c varying from 50 kN/m^2 to 200 kN/m^2 and ϕ varying from 5 to 30 degrees.

The results are obtained for all problems in terms of Capacity Factor of Euro Code wrt IS Code [2]. For the case of pure cohesionless soil and cohesive soil, the results are obtained by three approaches for Euro code viz.

- Euro-1: without considering type of shear failure based on angle of friction or cohesion and using general parameters for all values,
- Euro-2: considering type of shear failure based on characteristic values angle of friction or cohesion,
- Euro-3: considering type of shear failure based on factored values angle of friction or cohesion

For the case of C-ϕ soil, only general shear failure is considered. Plots of capacity factor wrt IS Code are shown in Figure-1 for Phi soil, in Figure-2 for C-Soil and Figure-3 and 4 for C-Phi soils.

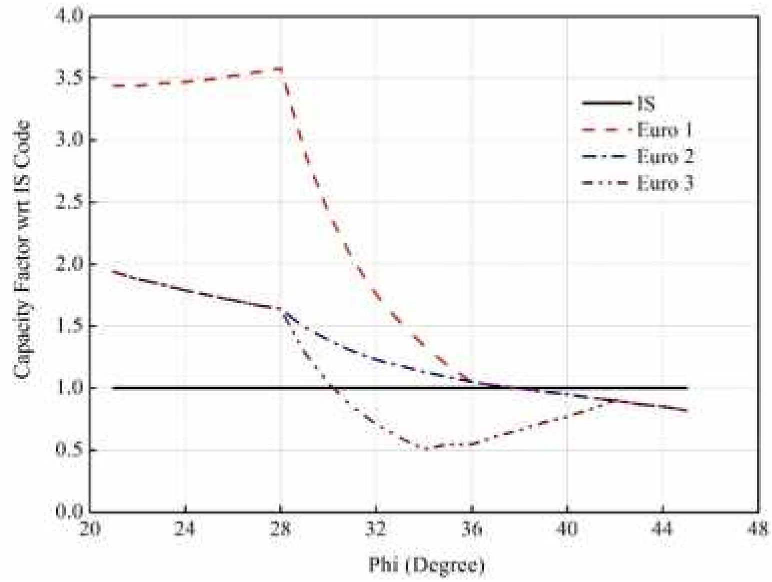

Fig. 1. Capacity Factor wrt IS Code for Phi Soil

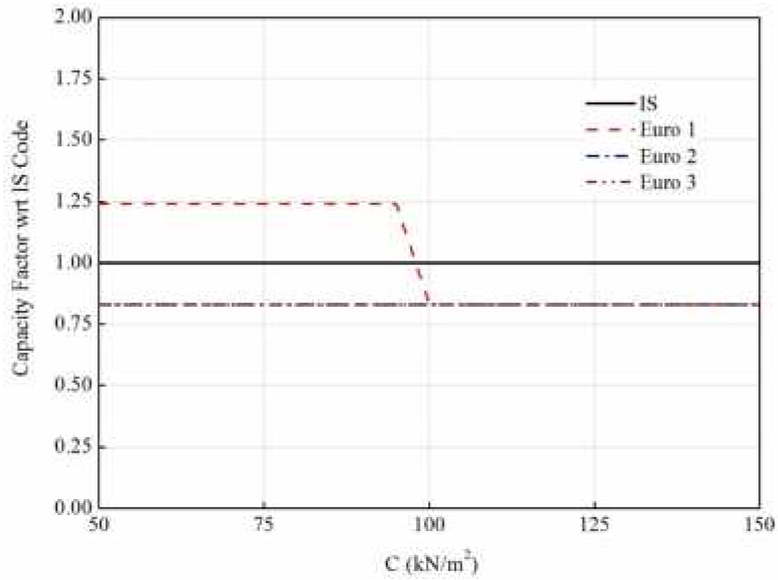

Fig. 2. Capacity Factor wrt IS Code for C Soil

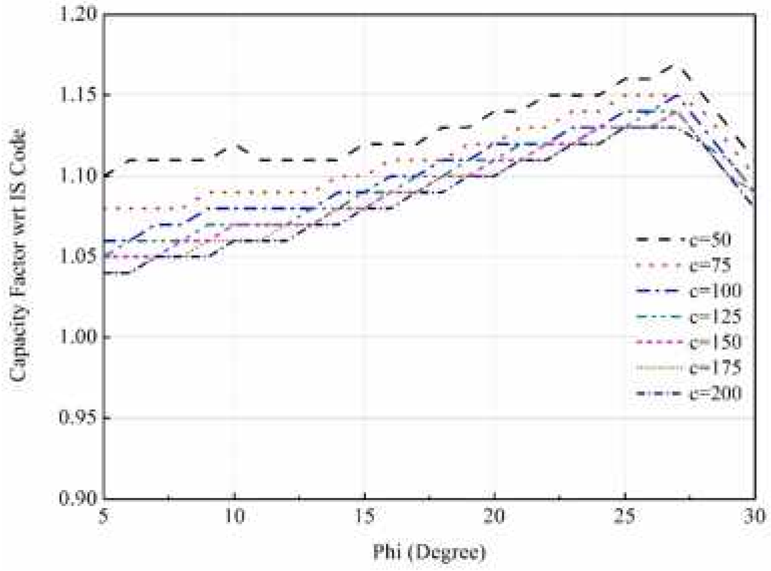

Fig. 3. Capacity Factor wrt IS Code for C-Phi Soil – 1

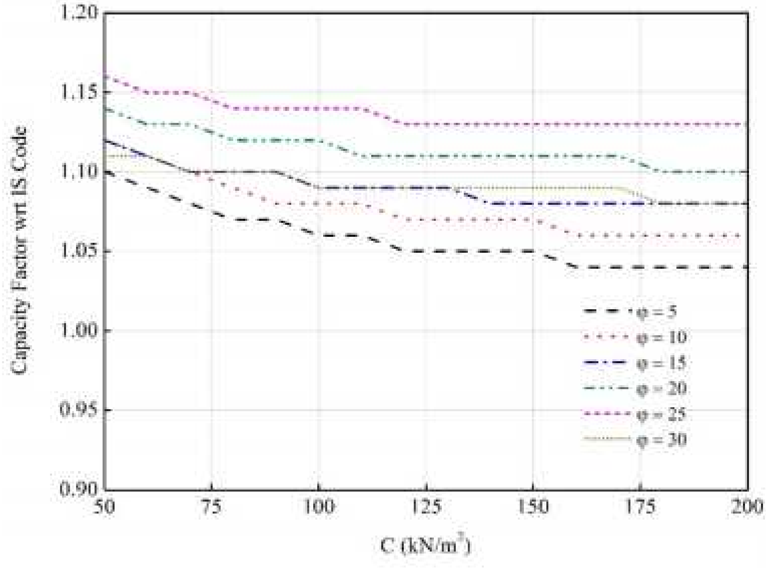

Fig. 4. Capacity Factor wrt IS Code for C-Phi Soil - 2

4 Conclusion

The aim of present paper is implementation of Eurocode – 7 (LRFD Method) for geotechnical design of shallow foundations and comparison of its results with IS code results. Parametric study has been carried out for c-soil, φ - soil and c- φ soil for given size and shape of foundation. As Eurocode is silent to guide for general shear or local shear failure calculations are made considering all possible options.

In all cases the comparison is made in terms of 'Capacity Factor' of Euro Code wrt IS Code. The Live Load is assumed as 20% of the Total Loads. From the obtained results, following conclusions are arrived at:

- c - soil: Characteristic value as Euro-3 case gives consistent results on lower side of IS code as 0.83.
- φ - soil: When shear failure is defined using characteristic value of φ, results are found rationale. The capacity ratio is 2.00 for φ = 24° and 0.82 for φ = 45°.
- c - φ soil: As both cases are considered for general shear failure, the variation remains from 1.02 to 1.15 which is very much convincing.

References

1. Borowiec A., "Some Economic aspects of EC7 – Introduction in Geotechnical Design on Example of Spread footing", Technical Transactions (2014)
2. Code of Practice for Determination of Breaking Capacity of Shallow Foundations, (First Revision), IS 6403 : 1981 (Reaffirmed 2002)
3. Frank R., Bauduin C, et. al, Designer's Guide to Eurocode 7: Geotechnical Design, ICE Publishing, Great Britain (2005)
4. Forrest W.S, Trevor L. L, "Reliability of shallow foundations designed to Eurocode 7", Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards, 4(4), 186-207 (2010)
5. Hansen J. B., "Revised and extended formula for bearing capacity", Danish Geotechnical Institute, Copenhagen, Bulletin, 28, 5–11 (1970)
6. Geotechnical Design – Part 1: General Rules, Eurocode 7 – EN 1997 : 2004
7. Terzaghi K., "Theoretical Soil Mechanics", New York, USA, John Wiley and sons (1943)
8. Trevor L. L., Proceedings of the International Conference on the Evaluation of Eurocode 7, Trinity College, Dublin (2005)