



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

EARTHQUAKE RESISTANT DESIGN OF FOUNDATIONS

Lecture 40: Codal Provisions

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ERD of Foundations - Modules

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2. Shallow Foundations
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Miscellaneous

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Chapter 4: Codal Provisions of ERD of Found.

- IS 1893, Part 1 (2016)
- **ASCE-7-16**

Increase in Net Pressure on Soils in Design of Foundations

- In the design of foundations, unfactored loads shall be combined in line with IS 2974, while assessing the bearing pressure in soils.
- When earthquake forces are included, net bearing pressure in soils can be increased as per Table 1, depending on type of foundation and type of soil.
- For determining the type of soil for this purpose, soils shall be classified in four types as given in Table 2.
- In soft soils, no increase shall be applied in bearing pressure, because settlements cannot be restricted by increasing bearing pressure.

Increase in Net Pressure on Soils in Design of Foundations

Table 1 Percentage Increase in Net Bearing Pressure and Skin Friction of Soils
(*Clause 6.3.5.2*)

Sl No. (1)	Soil Type (2)	Percentage Increase Allowable (3)
i)	<i>Type A:</i> Rock or hard soils	50
ii)	<i>Type B:</i> Medium or stiff soils	25
iii)	<i>Type C:</i> Soft soils	0

Increase in Net Pressure –Table 1 Continue (Notes)

- 1 The net bearing pressure shall be determined in accordance with IS 6403 or IS 1888.
- 2 Only corrected values of N shall be used.
- 3 If any increase in net bearing pressure has already been permitted for forces other than seismic forces, the increase in allowable bearing pressure, when seismic force is also included, shall not exceed the limits specified above.
- 4 The desirable minimum corrected field values of N shall be as specified below:

<i>Seismic Zone</i>	<i>Depth (m) below Ground Level</i>	<i>N Values</i>	<i>Remarks</i>
III, IV and V	≤ 5	15	For values of depths between 5 m and 10 m, linear interpolation is recommended
	≥ 10	25	
II	≤ 5	10	
	≥ 10	20	

Increase in Net Pressure –Table 1 Continue (Notes)

If soils of lower N values are encountered than those specified in the table above, then suitable ground improvement techniques shall be adopted to achieve these values. Alternately, deep pile foundations should be used, which are anchored in stronger strata, underlying the soil layers that do not meet the requirement.

- 5 Piles should be designed for lateral loads neglecting lateral resistance of those soil layers (if any), which are liable to liquefy.
- 6 Indian Standards IS 1498 and IS 2131 may be referred for soil notation, and corrected N values shall be determined by applying correction factor C_N for effective overburden pressure σ'_{vo} using relation $N = C_N N_1$, where $C_N = \sqrt{P_a / \sigma'_{vo}} \leq 1.7$, P_a is the atmospheric pressure and N_1 is the uncorrected SPT value for soil.

Increase in Net Pressure –Table 1 Continue (Notes)

- 7 While using this table, the value of N to be considered shall be determined as below:
- a) *Isolated footings* — Weighted average of N of soil layers from depth of founding, to depth of founding plus twice the breadth of footing;
 - b) *Raft foundations* — Weighted average of N of soil layers from depth of founding, to depth of founding plus twice the breadth of raft;
 - c) *Pile foundation* — Weighted average of N of soil layers from depth of bottom tip of pile, to depth of bottom tip of pile plus twice the diameter of pile;
 - d) *Group pile foundation* — Weighted average of N of soil layers from depth of bottom tip of pile group, to depth of bottom tip of pile group plus twice the width of pile group; and
 - e) *Well foundation* — Weighted average of N of soil layers from depth of bottom tip of well, to depth of bottom tip of well plus twice the width of well.

Issue of Liquefaction

- In soil deposits consisting of submerged loose sands and soils falling under classification SP with corrected standard penetration test values N , less than 15 in Seismic Zones III, IV and V, and less than 10 in Seismic Zone II, the shaking caused by earthquake ground motion may cause liquefaction or excessive total and differential settlements. Such sites should be avoided preferably for locating new structures, and should be avoided for locating structures of important projects.
- Otherwise, settlements need to be investigated, and appropriate methods adopted of compaction or stabilization to achieve N values indicated in Note 4 of Table 1. Alternatively, deep pile foundations may be adopted and anchored at depths well below the underlying soil layers, which are likely to liquefy or undergo excessive settlements.
- Also, marine clay layers and other sensitive clay layers are known to liquefy, undergo excessive settlements or even collapse, owing to low shear strength of the said soil; such soils will need special treatment according to site condition (see Table 2).
- A simplified method is given in Annex F, for evaluation of liquefaction potential.

**Table 2 Classification of Types of Soils for
Determining Percentage Increase in Net
Bearing Pressure and Skin Friction**
(Clause 6.3.5.2)

Sl No.	Soil Type	Remarks
(1)	(2)	(3)
i)	Type A Rock or hard soils	Well graded gravel (GW) or well graded sand (SW) both with less than 5 percent passing 75 mm sieve (Fines) Well graded gravel — sand mixtures with or without fines (GW-SW) Poorly-graded sand (SP) or Clayey sand (SC), all having N above 30 Stiff to hard clays having N above 30, where N is corrected standard penetration test value
ii)	Type B Medium or stiff soils	Poorly graded sands or poorly graded sands with gravel (SP) with little or no fines having N between 10 and 30 Stiff to medium stiff fine-grained soils, like silts of low compressibility (ML) or clays of low compressibility (CL) having N between 10 and 30

- | | |
|---|---|
| iii) Type C
Soft soils | All soft soils other than SP with $N < 10$. The various possible soils are:
Silts of intermediate compressibility (MI);
Silts of high compressibility (MH);
Clays of intermediate compressibility (CI);
Clays of high compressibility (CH);
Silts and clays of intermediate to high compressibility (MI-MH or CI-CH);
Silt with clay of intermediate compressibility (MI-CI); and
Silt with clay of high compressibility (MH-CH). |
| iv) Type D
Unstable, collapsible, liquefiable soils | Requires site-specific study and special treatment according to site condition (<i>see 6.3.5.3</i>) |

Design Acceleration Spectrum

For the purpose of determining design seismic force, the country is classified into four seismic zones as shown in Fig. 1.

The design horizontal seismic coefficient A_h for a structure shall be determined by:

$$A_h = \frac{\left(\frac{Z}{2}\right) \left(\frac{S_a}{g}\right)}{\left(\frac{R}{I}\right)}$$

Where, Z = seismic zone factor given in Table 3;

I = importance factor given in IS 1893 (Parts 1 to 5) for the corresponding structures; when not specified, the minimum value of I shall be

- a) 1.5 for critical and lifeline structures;
- b) 1.2 for business continuity structures; and
- c) 1.0 for the rest.

Fig. 1

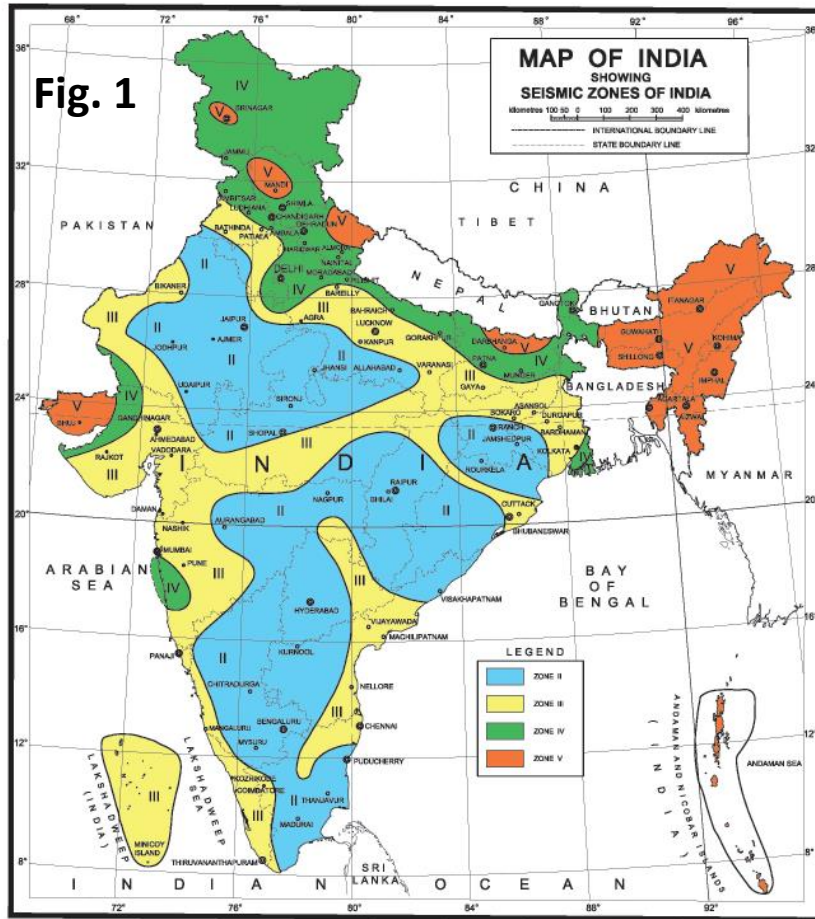


Table 3 Seismic Zone Factor Z
(Clause 6.4.2)

Seismic Zone Factor (1)	II (2)	III (3)	IV (4)	V (5)
Z	0.10	0.16	0.24	0.36

BIS 1893-Part I (2016)

R = response reduction factor given in IS 1893 (Parts 1 to 5) for the corresponding structures;

$\frac{S_a}{g}$ = design acceleration coefficient for different soil types, normalized with peak ground acceleration, corresponding to natural period T of structure (considering soil-structure interaction, if required). It shall be as given in Parts 1 to 5 of IS 1893 for the corresponding structures; when not specified, it shall be taken as that corresponding to 5 percent damping, given by expressions below:

a) For use in equivalent static method
[see Fig. 2(a)]:

$$\frac{S_a}{g} = \begin{cases} \text{For rocky or hard soil sites} & \begin{cases} 2.5 & 0 < T < 0.40 \text{ s} \\ \frac{1}{T} & 0.40 \text{ s} < T < 4.00 \text{ s} \\ 0.25 & T > 4.00 \text{ s} \end{cases} \\ \text{For medium stiff soil sites} & \begin{cases} 2.5 & 0 < T < 0.55 \text{ s} \\ \frac{1.36}{T} & 0.55 \text{ s} < T < 4.00 \text{ s} \\ 0.34 & T > 4.00 \text{ s} \end{cases} \\ \text{For soft soil sites} & \begin{cases} 2.5 & 0 < T < 0.67 \text{ s} \\ \frac{1.67}{T} & 0.67 \text{ s} < T < 4.00 \text{ s} \\ 0.42 & T > 4.00 \text{ s} \end{cases} \end{cases}$$

b) For use in response spectrum method
[see Fig. 2(b)]:

$$\frac{S_a}{g} = \begin{cases} \text{For rocky or hard soil sites} & \begin{cases} 1+15T & T < 0.10 \text{ s} \\ 2.5 & 0.10 \text{ s} < T < 0.40 \text{ s} \\ \frac{1}{T} & 0.40 \text{ s} < T < 4.00 \text{ s} \\ 0.25 & T > 4.00 \text{ s} \end{cases} \\ \text{For medium stiff soil sites} & \begin{cases} 1+15T & T < 0.10 \text{ s} \\ 2.5 & 0.10 \text{ s} < T < 0.55 \text{ s} \\ \frac{1.36}{T} & 0.55 \text{ s} < T < 4.00 \text{ s} \\ 0.34 & T > 4.00 \text{ s} \end{cases} \\ \text{For soft soil sites} & \begin{cases} 1+15T & T < 0.10 \text{ s} \\ 2.5 & 0.10 \text{ s} < T < 0.67 \text{ s} \\ \frac{1.67}{T} & 0.67 \text{ s} < T < 4.00 \text{ s} \\ 0.42 & T > 4.00 \text{ s} \end{cases} \end{cases}$$

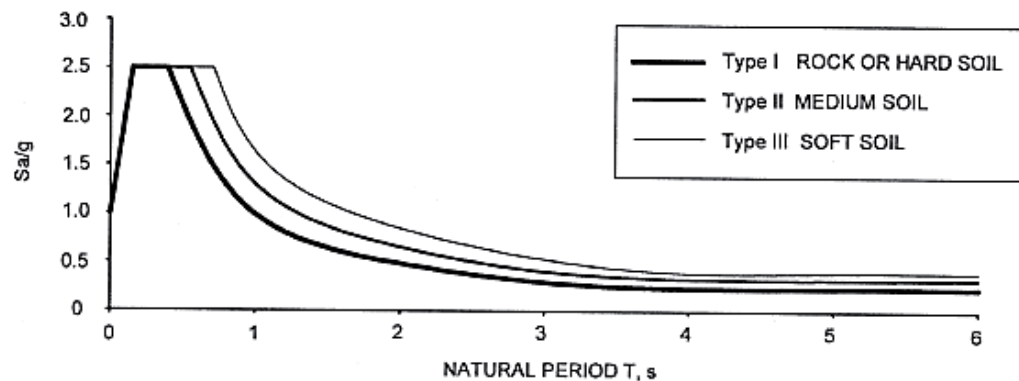
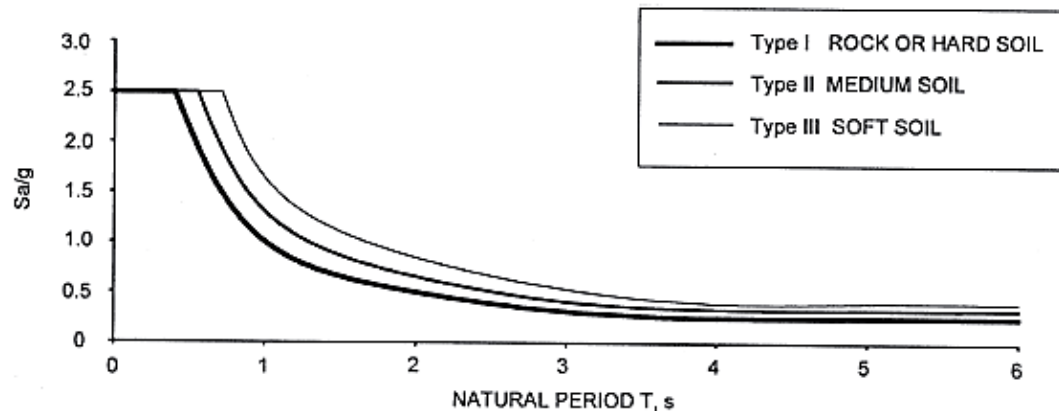


FIG. 2 DESIGN ACCELERATION COEFFICIENT (S_a/g) (CORRESPONDING TO 5 PERCENT DAMPING)

The Type of Soil

For determining the correct spectrum to be used in the estimate of (S_a/g) , the type of soil on which the structure is placed shall be identified by the classification given in Table 4, as:

- a) Soil type I — Rock or hard soils;
- b) Soil type II — Medium or stiff soils; and
- c) Soil type III — Soft soils.

In Table 4, the value of N to be used shall be the weighted average of N of soil layers from the existing ground level to 30 m below the existing ground level; here, the N values of individual layers shall be the corrected values.

**Table 4 Classification of Types of Soils for Determining the Spectrum to be Used to
Estimate Design Earthquake Force**
(Clause 6.4.2.1)

Sl No. (1)	Soil Type (2)	Remarks (3)
i)	I Rock or Hard soils	a) Well graded gravel (GW) or well graded sand (SW) both with less than 5 percent passing 75 μ m sieve (Fines) b) Well graded gravel-sand mixtures with or without fines (GW-SW) c) Poorly graded sand (SP) or clayey sand (SC), all having N above 30 d) Stiff to hard clays having N above 30, where N is standard penetration test value
ii)	II Medium or Stiff soils	a) Poorly graded sands or poorly graded sands with gravel (SP) with little or no fines having N between 10 and 30 b) Stiff to medium stiff fine-grained soils, like silts of low compressibility (ML) or clays of low compressibility (CL) having N between 10 and 30
iii)	III Soft soils	All soft soils other than SP with $N < 10$. The various possible soils are: a) Silts of intermediate compressibility (MI); b) Silts of high compressibility (MH); c) Clays of intermediate compressibility (CI); d) Clays of high compressibility (CH); e) Silts and clays of intermediate to high compressibility (MI-MH or CI-CH); f) Silt with clay of intermediate compressibility (MI-CI); and g) Silt with clay of high compressibility (MH-CH).

Chapter 4: Codal Provisions of ERD of Found.

- IS 1893, Part 1 (2016)
- ASCE-7-16

Foundation Design as per ASCE 7-16

The foundation shall be designed to resist the forces developed and to accommodate the movements imparted to the structure and foundation by the design ground motions. The dynamic nature of the forces, the expected ground motion, the design basis for strength and energy dissipation capacity of the structure, and the dynamic properties of the soil shall be included in the determination of the foundation design criteria.

Foundation Load-Deformation Characteristics

The linear load deformation behavior of foundations shall be represented by an equivalent linear stiffness using soil properties that are compatible with the soil strain levels associated with the design earthquake motion. The strain-compatible shear modulus, G , and the associated strain-compatible shear wave velocity, V_s , needed for the evaluation of equivalent linear stiffness shall be determined.

A 50% increase and decrease in stiffness shall be incorporated in dynamic analyses unless smaller variations can be justified based on field measurements of dynamic soil properties or direct measurements of dynamic foundation stiffness. The largest values of response shall be used in design.

Reduction of Foundation Overturning

Overtuning effects at the soil–foundation interface are permitted to be reduced by 25% for foundations of structures that satisfy both of the following conditions:

- a) The structure is designed in accordance with the equivalent lateral force analysis.
- b) The structure is not an inverted pendulum or cantilevered column type structure.

Overtuning effects at the soil–foundation interface are permitted to be reduced by 10% for foundations of structures designed in accordance with the modal analysis

Nominal Strength

The nominal foundation geotechnical capacity, Q_{ns} , shall be determined using any of the following methods:

1. presumptive load-bearing values,
2. by a registered design professional based on geotechnical site investigations that include field and laboratory testing to determine soil classification and as-required active, passive, and at-rest soil strength parameters, or
3. by in situ testing of prototype foundations.

Nominal strength values are permitted to be based on either a limitation of maximum expected foundation deformation, or by the nominal strength that is associated with an anticipated failure mechanism

Nominal Strength (Continued...)

Soil Strength Parameters

- For competent soils that do not undergo strength degradation under seismic loading, strength parameters for static loading conditions shall be used to compute nominal foundation geotechnical capacities for seismic design unless increased seismic strength values based on site conditions are provided by a registered design professional.
- For sensitive cohesive soils or saturated cohesionless soils, the potential for earthquake-induced strength degradation shall be used.

Resistance Factors

The resistance factors shall be used for vertical, lateral, and rocking resistance of all foundation types. Nominal foundation geotechnical capacities, Q_{ns} , shall be multiplied by the resistance factors (ϕ) shown in Table. Alternatively, a vertical resistance factor, $\phi = 0.80$ is permitted to be used when the nominal strength is determined by *in situ* testing of prototype foundations.

Direction and Type of Resistance	Resistance Factors, ϕ
<i>Vertical Resistance</i>	
Compression (bearing) strength	0.45
Pile friction (either upward or downward)	0.45
<i>Lateral Resistance</i>	
Lateral bearing pressure	0.5
Sliding (by either friction or cohesion)	0.85

Pile–Soil Interaction

Pile moments, shears, and lateral deflections used for design shall be established considering the interaction of the shaft and soil. Where the ratio of the depth of embedment of the pile to the pile diameter or width is less than or equal to 6, the pile is permitted to be assumed to be flexurally rigid with respect to the soil.

Pile Group Effects. Pile group effects from soil on lateral pile nominal strength shall be included where pile center to center spacing in the direction of lateral force is less than eight pile diameters or widths. Pile group effects on vertical nominal strength shall be included where pile center-to-center spacing is less than three pile diameters or widths.

Requirements for Foundations on Liquefiable Sites

Soil strength loss caused by liquefaction in MCE_G earthquake motions, structures shall be designed to accommodate the effects of liquefaction in accordance with the requirements of Sections 12.13.9.1 through 12.13.9.3.

Foundation Design

Foundations shall be designed to support gravity and design earthquake loads, using the reduced soil bearing capacity, considering the effects of liquefaction caused by MCE_G earthquake motions. The anticipated lateral spreading, differential settlement values, and foundation design shall be permitted to include the mitigating effects of any planned ground improvements for the site.

References

1. **IS: 1893 (2016), “Criteria for Earthquake Resistant Design of Structures, Part 1: General Provisions and Buildings”, Bureau of Indian Standards, New Delhi**
2. **IS 6403 (1981) : Code of practice for determination of bearing capacity of shallow foundations by Bureau of Indian Standards (BIS), New Delhi**
3. **ASCE/SEI 7-16 (2016), “Minimum Design Loads and Associated Criteria for Buildings and Other Structures,” American Society of Civil Engineers**

Thank You

