

27. Earthquake Consideration in Infrastructure Project Sector

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27 Earthquake Considerations in Infrastructure Project

27.1 Introduction

Nepal is located in the tectonically active belt of the Himalayas. The Himalayas were formed as a result of the collision between the Indian and Eurasian Subcontinents about 40 million years ago. The process of convergence is still continuing and hence the Himalayan region is highly earthquake prone. Nepal is situated in the southern lap of the Himalayas where active geological features are present. The main boundary thrust is the most active thrust and runs from east to west along the southern belt of Nepal while the main central thrust is a moderately active thrust and runs from east to west along the northern belt. Apart from these major thrusts, various other geological features are present in Nepal many of them still tectonically active. These geological conditions make Nepal vulnerable to frequent occurrences of earthquakes.

Due to this sensitivity to earthquakes, infrastructure projects require for due consideration of earthquakes in the planning, design, construction and use of structures. The present practice is to follow the seismic zone map of India where the entire Indian subcontinent is divided into five seismic zones. Nepal is located in zones 4 and 5, which are considered severe in the Indian Subcontinent. Earthquake consideration is not mandatory for most infrastructure projects but it is wise to apply it in important buildings, bridges, overhead tanks, hydropower structures and tower designs.

27.2 Applicability of Guidelines

The proposed guidelines for earthquake considerations shall apply to the following categories of structures in conjunction with reference documents listed in Table 27.1:

- All buildings having a plinth area greater than 20 m² or height ranging from 5 m to 90 m.
- All masonry and concrete walls having a height of greater than 1.5 m.
- All elevated water tanks and silos with capacity up to 200 m³.
- All public buildings having general public access.
- All civil engineering structures such as bridges, dams, earth structures, silos, water tanks, chimneys etc.
- All towers and electric or telecom or radio pylons.

The requirements of these guidelines shall be followed at minimum. The designer is however free to exercise more stringent procedures if considered necessary considering the merit of the case.

27.3 Institutional Arrangements

There is no single institution responsible for all earthquake matters in different public works sectors in Nepal. The following agencies are responsible for various earthquake matters:

- Department of Mines and Geology is responsible for earthquake instrumentation network in the country and preparation of the seismic zone map of the country.
- National Bureau of Standards and Metrology is responsible for the certification of standards and constituents of codes and guidelines on various public works including earthquake matters.
- National Building Council is envisaged as an apex body to deal with the creation and updating of the National Building Code of Nepal.
- Department of Urban Planning and Housing is responsible for the creation and implementation of National Building Codes for Nepal including earthquake matters.

- Local bodies (VDCs, DDCs and Municipalities) are responsible for formulation and/or adoption of bylaws, codes, norms, regulations and enforcing / policing their implementation in the areas of their jurisdiction.

27.4 Donor Involvement

In the area of earthquake projects, donor agencies involved include UNCHS, UNESCO and JICA.

27.5 National Policy

The recent earthquakes (1988 in Udayapur, Nepal and 2001 in Gujarat, India) have prompted serious concerns for the earthquake safety of infrastructure. It is therefore relevant that these PWD should address earthquake considerations for the planning and design of infrastructure.

Following the major earthquake event in 1988, the Ministry of Physical Planning and Works (previously, Ministry of Housing and Physical Planning) undertook a policy initiative jointly with UNDP and UNCHS to address need for changes in current building design and construction methods. The UNDP / UNCHS (Habitat) Project and the Ministry undertook "Policy and Technical Support to Urban Sector Project" under which national housing survey, shelter sector training needs assessment, draft national housing policy formulation, draft national building code preparation etc. were undertaken. The national building code development project also prepared a draft of 'Building Act' to facilitate the regulation of building design / construction practice in Nepal and a draft of 'Engineering Council Act' to facilitate self regulation of the profession by professionals. The project completed preparation of the National Building Codes in 1994. The National Building Code consists of a set of 20 separately bound documents. The National Building Codes comply with the general requirements of the Nepal Bureau of Standards and Meteorology which are now awaiting approval by the HMGN.

The reference documents for earthquake considerations for infrastructure are presented in Table 27.1.

Table 27.1 Reference Documents for Earthquake Considerations for Infrastructures

Document	Description
National Building Code 105,1994	<i>Seismic Design of Buildings in Nepal</i>
National Building Code 108, 1994	<i>Site Consideration</i>
National Building Code 201, 1994	<i>Mandatory Rule of Thumb – Reinforced Concrete Buildings with Masonry Infill</i>
National Building Code 202, 1994	<i>Mandatory Rule of Thumb – Load Bearing Masonry</i>
National Building Code 203, 1994	<i>Guidelines for Earthquake Resistant Building Construction: Low Strength Masonry</i>
National Building Code 204,1994	<i>Earthquake Resistant Building Construction: Earthen Buildings</i>
National Building Code 205, 1994	<i>Mandatory Rule of Thumb – Reinforced Concrete Buildings without Masonry Infill</i>
National Building Code 300,	<i>Illustrative Design Guidelines for Reinforced Concrete Ductile Bare Moment Resistant Frame Building</i>
UNESCO Educational Building Report 13	<i>Protection of Educational Buildings Against Earthquakes (under revision by NSET – Nepal)</i>
Indian Standard 1893, 1984	<i>Criteria for Earthquake Resistant Design of Structures (under revision)</i>

Document	Description
Indian Standard 4326, 1993	<i>Earthquake Resistant Design and Construction of Buildings - Code of Practice</i>
Indian Standard 13287, 1993	<i>Improving Earthquake Resistance of Earthen Buildings - Guidelines</i>
Indian Standard 13828, 1993	<i>Improving Earthquake Resistance of Low Strength Masonry Buildings – Guidelines</i>
Indian Standard 13920, 1993	<i>Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces – Code of Practice</i>
Indian Standard 13935, 1993	<i>Repair and Strengthening of Buildings - Guidelines</i>
National Building Code of India, 1983	<i>National Building Code of India, Part VI Structural Design, Section I Loads, Chapter 5 Seismic Load</i>
Eurocode 8 Prestandard	<i>Design Provisions for Earthquake Resistance of Structures</i>
USBR Manual	<i>Design of Small Dams</i>

Apart from these, no other guidelines are available to address earthquake issues specifically in Nepal and therefore these PWD attempt to provide guidelines in a comprehensive manner.

27.6 Objective

The objective of these guidelines is to ensure during and after an earthquake event:

- Human lives are protected,
- Damage is limited, and
- Civil protection structures remain operational.

The scope of these guidelines covers design and construction of civil and structural works. These guidelines shall take precedence to National Standard, Indian Standard and Eurocodes on aspects included herein.

The guidelines are not intended to apply to special structures such as nuclear power plants, large dams, blast proof designs and tall buildings.

27.7 General Principles

- Earthquakes cause vibration on the ground and in structures which may be resolved in three orthogonal directions. The predominant direction of vibration is horizontal.
- The ground vibration intensity depends on the magnitude of the earthquake, depth of focus, distance from epicentre and subsoil type.
- The response of a structure depends on subsoil type, construction type and material, duration, intensity of ground vibration and frequency of content of motion.
- For a structure designed considering horizontal seismic forces only, it will act in one direction at a time. For a structure designed considering both horizontal and vertical seismic forces, the vertical seismic force (upward or downward) will be simultaneously considered with horizontal seismic force in each direction separately.
- The vertical seismic force is considered only for a structure where stability criterion is applicable.

- Structural analysis is not always necessary. Simple precautions in construction help add to the resistance to withstand seismic forces, for example:
 - Suitably proportioned diagonal bracings in vertical panel of steel and concrete structures.
 - Selection of type of construction materials such as lightweight materials and well braced timber framed structures.
 - Earthquake resistance of conventional masonry structure may be greatly improved by following good practice guides.

27.8 Assumptions

The following assumptions are made in the seismic resistant design of structures:

- Designs are prepared by appropriately qualified and experienced personnel.
- Adequate supervision and quality systems are provided during execution of the works.
- Construction is carried out by personnel having the appropriate skill and experience.
- Construction materials and products conform to the pertinent codes and specifications.
- The structure is adequately maintained.
- The structure is used in accordance with the design brief.
- An earthquake is not likely to occur simultaneously with maximum flood, wind, waves or tides.
- Resonance as visualized under steady state sinusoidal excitations will not occur, as the small duration of earthquake is not enough to build up resonance amplitudes.
- Subsoil does not considerably settle or slide due to earthquake at the site of structure.

27.9 Methods of Analysis

The analysis for the design of earthquake action shall be carried with the following methods:

- Seismic coefficient method
- Modal response spectrum method

Salient features of the two methods of earthquake analysis are given in Table 27.2.

Table 27.2 Methods of Earthquake Analysis

Particulars	Seismic Coefficient Method	Modal Response Spectrum Method
Applicability of methods	For simple building structures not higher than 40 m	For simple building structures higher than 40 m. All buildings with irregular configurations, unusual shape, size or importance, abrupt changes in lateral resistance, lateral stiffness with height. Special, complicated and highly important structures.
Assumptions	Seismic force is obtained as a product of mass and design seismic coefficient.	The structure is represented with analytical model.

Particulars	Seismic Coefficient Method	Modal Response Spectrum Method
	Design seismic coefficient is uniform over the entire structure. Linear distribution of horizontal seismic acceleration from zero at bottom to maximum at top.	Minimum of three modes should be considered. The building structure is considered as a flexible structure with lumped masses at floor levels with one degree of freedom for displacement in horizontal direction.
Limitations	Not applicable for unusually important and complicated structures. The seismic action is oversimplified to static analysis.	For small structures, the effort for spectral analysis is too elaborate. The seismic action is complicated and involves dynamic analysis.
Horizontal seismic coefficient	$C_d = CZIK$	$C_d(T_i) = C(T_i)ZIK$
Percentage of live load to be considered	25% up to 3kN/m^2 and 50% above 3kN/m^2 No live load at roof level	

27.10 Subsoil Characterization

The ground condition should be investigated to assess the earthquake effects. The ground for a structure must be free from rupture, slope instability or permanent settlement caused by liquefaction or densification. The possibility of liquefaction and densification should be investigated. For structures of low importance, no ground investigation is required and subsoil type II may be assumed. The subsoil characterization based on National Building Code 105, 1994 is given in Table 27.3 and corresponding basic seismic coefficients can be obtained from Figure 27.1. An alternative subsoil characterization using *Eurocode 8 prestandard* based on shear velocity profile is also provided for simplicity in Figure 27.2.

Table 27.3 Subsoil Characterization to Determine Basic Seismic Coefficient (C)

Subsoil Type I: Rock or Soil Sites (Typical low amplitude natural period < 0.2 s) Sites with bedrock, including weathered rock with an unconfined compressive strength > 500 kPa, overlain by less than 20 m of: • Very stiff cohesive soil with UCS > 100 kPa • Very dense non-cohesive soil with N > 30	Subsoil Type II: Medium Soil Sites (Typical low amplitude natural period 0.2 – 0.6 s) Subsoil not included in Type I and Type III.																																	
Subsoil Type III: Soft Soil Sites (Typical low amplitude natural period > 0.6 s)																																		
Cohesive Soils <table><tr><th>Cohesive Soil Classification</th><th>Representative Undrained Shear Strength (kPa)</th><th>Depth of Soil (m) Exceeding</th></tr><tr><td>Soft Clay</td><td>12.5-25</td><td>20</td></tr><tr><td>Firm Clay</td><td>25-50</td><td>25</td></tr><tr><td>Stiff Clay</td><td>50-100</td><td>40</td></tr><tr><td>Very Stiff Clay</td><td>100-200</td><td>60</td></tr></table>	Cohesive Soil Classification	Representative Undrained Shear Strength (kPa)	Depth of Soil (m) Exceeding	Soft Clay	12.5-25	20	Firm Clay	25-50	25	Stiff Clay	50-100	40	Very Stiff Clay	100-200	60	Non-cohesive Soils <table><tr><th>Non-cohesive Soil Classification</th><th>Representative SPT Value (N)</th><th>Depth of Soil (m) Exceeding</th></tr><tr><td>Loose</td><td>4-10</td><td>40</td></tr><tr><td>Medium Dense</td><td>10-30</td><td>45</td></tr><tr><td>Dense</td><td>30-50</td><td>55</td></tr><tr><td>Very Dense</td><td>>50</td><td>60</td></tr><tr><td>Gravels</td><td>>30</td><td>100</td></tr></table>	Non-cohesive Soil Classification	Representative SPT Value (N)	Depth of Soil (m) Exceeding	Loose	4-10	40	Medium Dense	10-30	45	Dense	30-50	55	Very Dense	>50	60	Gravels	>30	100
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27.11 Seismic Zones

- National seismic zones are as presented in Figure 27.3.
- Return period for seismic event should be usually 300 years corresponding to an importance factor of 1.0.

27.12 Basic Representation of Seismic Action

Seismic Coefficient Method

In the seismic coefficient method, the horizontal seismic coefficient is obtained as product of zone coefficient (Z from Figure 27.3), basic seismic coefficient (C from Figure 27.1), importance factor (I from Table 27.4) and structure performance factor (K from Table 27.5).

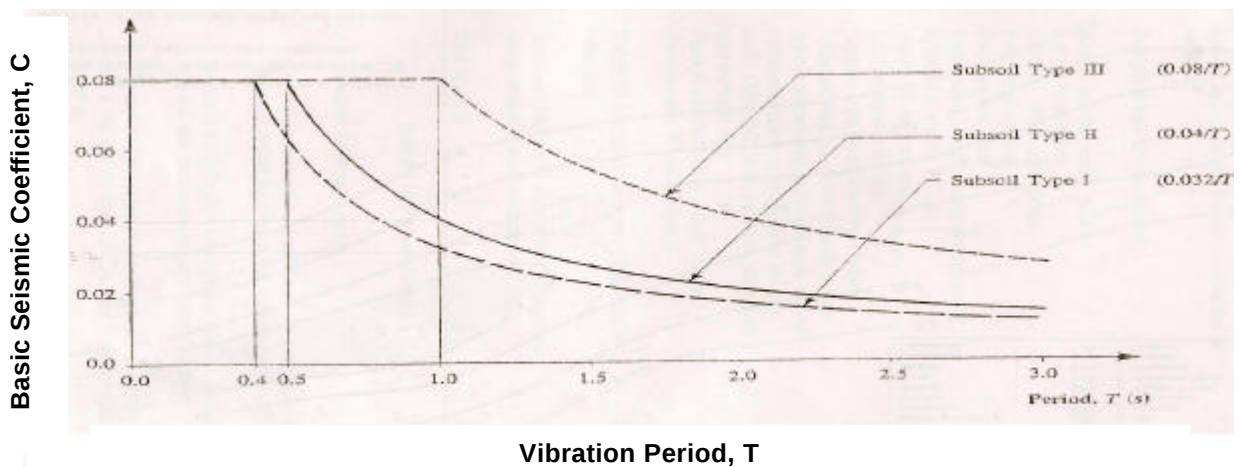
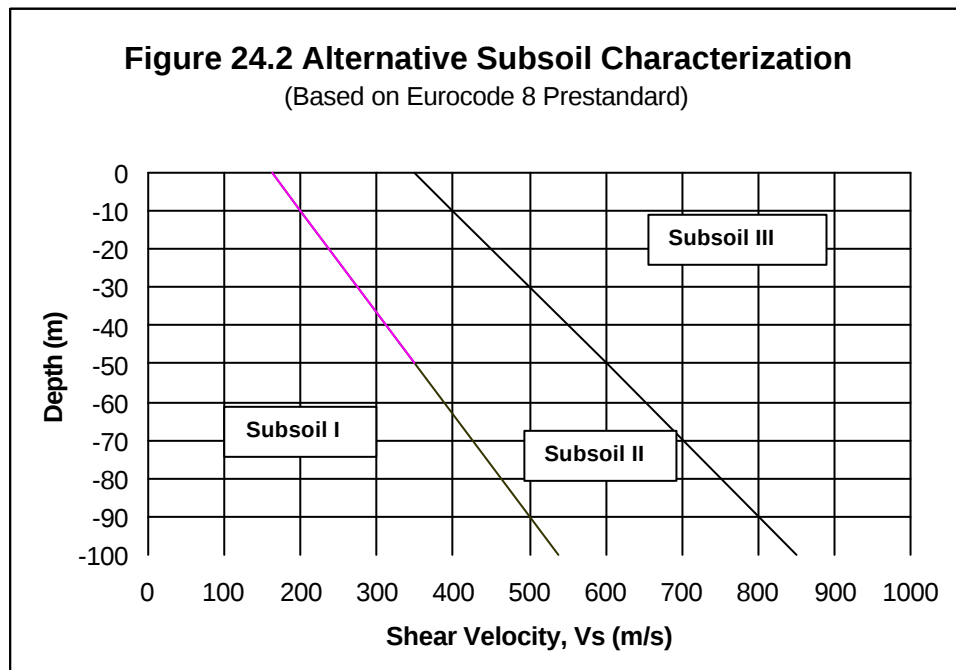


Figure 27.1 Determination of Basic Seismic Coefficient



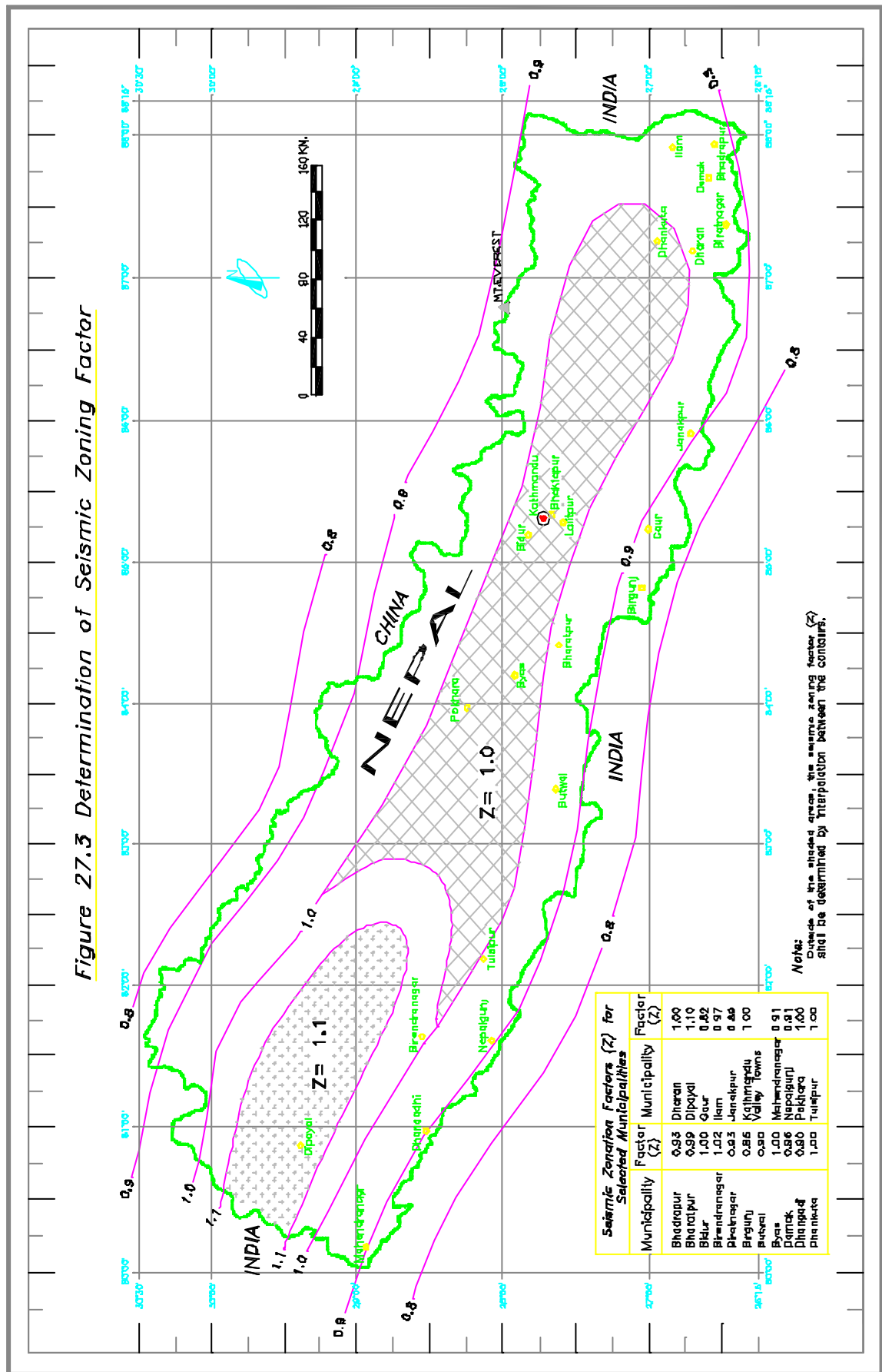


Figure 27.3 Determination of Seismic Zoning Factor

Table 27.4 Importance Factor (I)

Type of Structure	Importance Factor (I)
1. Essential facilities that should remain functional after an earthquake such as: – Hospitals and other medical facilities – Fire and police stations – Emergency vehicle shelters / garages – Food storage structures – Emergency relief stores – Power stations / standby generators – Water works and water towers – Radio and TV facilities – Telephone exchanges / transmission – Office and residential quarters – Places of assembly	1.5
2. Monumental buildings	1.5
3. Distribution facilities for gas or petroleum products in urban area	2.0
4. Structures for the support or containment of dangerous substances such as acids, toxic substances etc.	2.0
5. Other structures	1.0

Table 27.5 Structural Performance Factor (K)

Item	Structural Type		Minimum Detailing Requirements	Structural Performance Factor (b)
1a	Ductile moment resisting frame	Normal	Comply with IS 13920,1993 and NBC 111	1.0
1b		With RCC shear walls	Comply with IS 13920,1993 and NBC 111	1.0
2a		With either steel bracing members or RCC infill panels	Comply with IS 13920,1993, NBC 110 and NBC 111	1.5
2b		With masonry infill	Comply with IS 13920,1993	2.0
3	Diagonally braced steel frame with ductile bracing acting in tension only		Comply with Nepal Steel Construction Standard	2.0
4	Cable stayed chimneys		Appropriate material standard	3.0
5	Structures of minimum ductility including RCC frames and masonry bearing walls		Appropriate material standard	4.0

Seismic Spectrum Method

In the seismic spectrum method, the basic representation of seismic action is made as follows:

- Earthquake motion is represented by elastic response spectrum as shown in Figure 27.4.
- Horizontal seismic action is resolved into two independent orthogonal components with the same elastic response spectrum.
- The elastic response spectrum for vertical component will be similar to that for the horizontal elastic response spectrum with reduction as follows:
 - For $T < 0.2s$, reduce to 0.7 times.
 - For $0.2s < T < 0.6s$, interpolate reduction between 0.7 and 0.5 times.
 - For $T > 0.6s$, reduce to 0.5 times.
- For special conditions, multiple elastic response spectra may be applied.
- For mountainous areas, topographic amplification factors should be used.

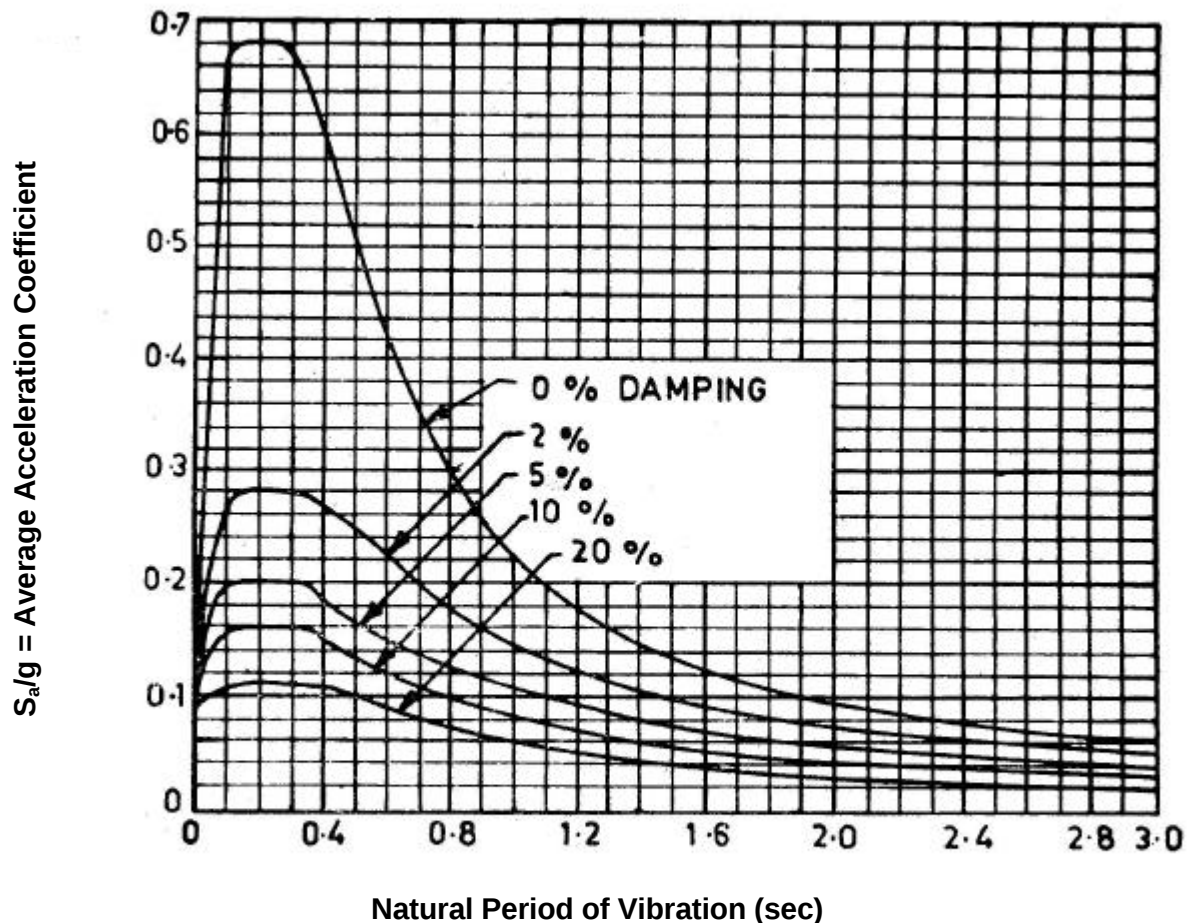


Figure 27.4 Seismic Acceleration Coefficient

27.13 Methods of Design

The design of structures shall be in accordance with:

- Working stress method (not preferred)
- Limit state method (preferred)

The salient features of the two methods of design are given in Table 27.6.

Table 27.6 Methods of Earthquake Designs

Particulars / Parameters	Working Stress Method (not preferred)	Limit State Method (Preferred)
Load combinations [DL=dead load, LL=live load, E=earthquake load, SL=snow load]	DL + LL + E 0.7 DL + E DL + SL + E	DL + 1.3 LL + 1.25 E 0.9 DL + 1.25 E DL + 1.3 SL + 1.25 E
Permissible increase in material stresses	May be increased by one third for steel, timber and concrete but shall not exceed • Yield stress for materials with definite yield strength • 80% of ultimate strength or 0.2% proof stress whichever is smaller for materials without definite yield strength • Two thirds of modulus of rupture for pre-stressed concrete members.	No increase permitted but partial safety factors are reduced as above.
Permissible increase in allowable soil bearing pressure	May be increased by up to 50% (Refer Table 27.7 for details)	No increase permitted but partial safety factors may be reduced by one third.
Method of RCC design	Limit State Method	Limit State Method

Table 27.7 Permissible Increases in Allowable Bearing Pressure or Resistance of Soils

Type of Soil	Type of Foundation	Permissible Increase (%)
Type I: Rock or Hard Soils	All types of foundations	50
Type II: Medium Soils	Piles passing through this soil but resting on Type I soil	50
	Piles not covered under above	25
	Raft foundation	50
	Other type of foundations	25
Type III: Soft Soils	Piles passing through this soil but resting on Type I soil	50
	Piles not covered under the above	25
	Raft foundations	50
	Combined or isolated RCC footing with tie beams	25
	Isolated RCC footing without tie beams	0
	Un-reinforced strip foundations	0
	Well foundations	25

The limit state is further broken down into two categories:

- Ultimate Limit State where:
 - Behaviour factor is equal to 1.0 for non-dissipative structures; is greater than 1.0 for dissipative zones.
 - Overturning and sliding stability needs to be checked.
 - Ability of foundation elements and foundation-soil system to resist foundation pressures without substantial deformation should be checked.
- Serviceability Limit State where:
 - Deformation limits for functional requirement should be checked.
 - Structure should possess resistance and stiffness to maintain integrity.

27.13.1 Design of multi-storey buildings

27.13.1.1 General

- Buildings with rigid horizontal diaphragm action shall be analysed as a whole for seismic forces. The total shear in any horizontal plane shall be distributed to various elements of lateral forces resisting system assuming the floors to be infinitely rigid in horizontal plane.
- In buildings with shear walls together with frames, the frames shall be designed for at least 25% of the seismic shear.
- In buildings without diaphragm action by floors, the building frames behave independently and may be analysed frame by frame for seismic forces.
- The methods recommended for various categories of structures are given in Table 27.8.
- Consideration of drift and torsion is desirable for all building structures but is particularly essential for building with heights above 40 m.

27.13.1.2 Design Eccentricity

- The design eccentricity e_d shall be determined as follows:
- If $e_c < 0.1 b$ and the building is ≤ 4 storeys, $e_d = 0$.
- If $e_c < 0.3 b$, $e_d = e_c + 0.1 b$ or $e_d = e_c - 0.1 b$ whichever is the most severe for the element under consideration.
- If $e_d > 0.3 b$, the structure should be analysed using a three dimensional modal response spectrum analysis with the mass at each level displaced by $\pm 0.1 b$, whichever is the most severe for the element under consideration.
- Where,
- b = maximum horizontal dimension of the building at the particular level measured perpendicular to the direction of loading.
- e_c = computed eccentricity of the center of mass from the centre of rigidity.
- e_d = design eccentricity of the seismic load at a particular level.

27.13.1.3 Inter-Storey Deflection

- The ratio of the inter-storey deflection to the corresponding storey height shall not exceed 0.01 nor the inter-storey deflection exceeds 60 mm.

27.13.1.4 Static Analysis for Torsional Effects

- For the static analysis for torsional effects, the applied torsion at each level shall use either the forces calculated by the seismic coefficient method or the combination storey inertial forces found in a translational two dimensional modal response spectrum analysis and design eccentricity, e_d calculated as above.

- The torsional effects shall be combined with the translational effects by direct summation, with signs chosen to produce the most adverse combined effects in the elements under consideration.

27.13.1.5 Three Dimensional Analysis

- For each direction of loading the position and distribution of the mass at each level shall be adjusted to account for an eccentricity about the centre of mass of $\pm 0.1 b$. The sign of the eccentricity shall be such that producing the largest design action in the element under consideration.

27.13.2 Design of Elevated Tower Supported Tanks

The designer should be extra careful in design of vertical and horizontal projections such as towers, tanks, chimneys, balconies and cantilever projections. Such systems are subject to larger motions than buildings. The seismic coefficient for the seismic design of horizontal and vertical projections should be multiplied by 5 times both for horizontal and vertical directions. The seismic coefficients for main structures should however not be altered.

No empirical formulas are available for predicting the vibration period of water towers. Water towers generally have longer periods and effective acceleration coefficients are smaller than the peak of the acceleration response spectra. The seismic coefficient method does not use this reduction. The response spectrum method is recommended for analysis and design of elevated tower supported structures in all seismic zones. Alternatively, a reduction factor of 0.75 may be applied with the seismic coefficient method. The equivalent mass of a water tank will be taken as:

$$\begin{array}{ll} M = m + m_0/3 & \text{for } m > m_0 \\ M = m + m_0/2 & \text{for } m < m_0 \end{array}$$

Where,

M = equivalent mass of tank and staging

m = mass of tank alone

m_0 = mass of staging alone.

Hydrodynamic Pressure in Tanks

A tank containing fluid with a free surface is subjected to earthquake ground motion. It experiences dynamic fluid pressures of two types. Firstly, when the walls of the tank accelerate, the adjacent fluid also accelerates and exerts an impulsive pressure on the wall, which is directly proportional to the acceleration of the wall. Secondly, the effect of the impulsive pressure exerted by the wall on the fluid is to excite the fluid into oscillation and the oscillatory acceleration of the fluid produces convective pressures on the walls and bottom whose amplitudes are proportional to the amplitude of oscillation. The convective pressures are small compared to impulsive pressures and hence are neglected. For a tank resting on ground the acceleration of fluid is same as that of peak ground acceleration while for elevated tanks, the acceleration of fluid corresponds to the response acceleration of the tank.

27.13.3 Design of Stack-Like Structures

The mass and stiffness of stack-like structures are uniformly distributed along the height. The structures may have uniform or tapered sections. The structure may be treated as a cantilever beam for the purpose of earthquake analysis. Bending deformations are predominant in stack-like structures but general shear and rotary inertial deformations should also be considered.

The provisions should not apply to the cases where concentrated masses are located at some levels or to structures supported on staging like silos. The provisions also assume that the foundation conditions are reasonably good and the structure is fixed at the foundation level.

27.13.4 Design of Bridges

The safety of a bridge as a whole and that of its superstructure, bearings, piers and foundation is important during an earthquake. The two directions critical for earthquake-resistant design are the bridge axis and the perpendicular to it. The horizontal seismic force is assumed to act in one of these directions at a time. For the purpose of design, a bridge could be divided into elements, such as superstructure, bearing, piers etc. The seismic force equal to the weight of the element times the design seismic coefficient should be applied at the centre of gravity of the element.

Masonry arch bridges are most vulnerable to damage during earthquakes due to brittleness and hence they are not recommended for span more than 10 m nor for multiple spans. Slab, box and pipe culverts are not to be designed for earthquake forces. All RCC, plate girder and truss bridges should be designed for earthquake forces. The seismic coefficient method may be applied in most cases.

Special types of bridges such as suspension, cable stayed, horizontally curved, reinforced concrete arch or steel bridge types and bridges with piers taller than 30 m or spans more than 60 m are susceptible to structural vibrations. Dynamic analysis with modal response spectrum is recommended for such special bridges.

The effective live load is 25% of the design live load for road bridges and 50% for railway bridges. As earthquake and maximum flood do not occur simultaneously, only scour depth caused by mean annual flood should be considered in combination with earthquake loads. The superstructure should be designed for vertical seismic force as well. The effective live load for vertical seismic force is 50% on road bridges and 100% in railway bridges.

Anchor bolts should be designed for horizontal seismic force on the girder. To prevent dislodging of rollers, connecting plates or segmental rollers or stoppers should be used. To avoid jumping of girders, special hooks must be employed connecting the top and bottom shoes.

To avoid overturning of super structure in the transverse direction, a factor of safety of 1.5 against overturning should be ensured. While considering the stability, the vertical seismic force giving the worst effect should be considered in combination with the horizontal seismic force. Horizontal and vertical seismic forces on the piers and wells should be applied at their centre of masses. The uplift or buoyancy forces are not considered, as they are not inertial forces. Additional dynamic force in the form of hydrodynamic force should be considered for the submerged portion of the piers.

27.13.5 Design of Gravity Dams

The design of gravity dams must reasonably anticipate the most severe earthquake that does not impair the function of the structure.

Earthquakes impart accelerations and increase effective loading on the dam. Both horizontal and vertical earthquake forces should be considered in a way to produce the least stable condition. For full reservoir conditions, this will be a foundation movement in the upstream and downward direction. The upstream movement increases the downstream force of water and silt loads and produces a downstream inertial force from the mass concrete in the dam. The downward movement decreases the effective weight of the water above a sloping face and of the concrete in the dam. The increase in horizontal loads in a downstream direction and decrease in effective weights decrease the stability of the dam.

The earthquake intensity or acceleration is expressed in relation to the acceleration due to gravity. The accelerations that may be reasonably expected at the dam site are determined from a consideration of the geology of the site, proximity to major faults, previous earthquake history of the region, and available seismic records.

The internal friction of silt provides considerable damping. However, it is assumed that the dynamic effect of saturated silt is equivalent to that of water only.

Resonance in low dams is unlikely to occur during earthquakes. The fundamental period of vibration of a concrete dam 15 m high (low dam) and of triangular cross section, is 0.03 - 0.04 s. Vibration periods of important earthquakes range within 0.20 - 0.60 s. Therefore, resonance is unlikely to take place in low dams.

Zangar (1952) presented a formula for computing the hydrodynamic pressure exerted on vertical and sloping faces by horizontal earthquake. The formula was derived by electrical analogy assuming water to be incompressible. For low dams the error involved in computing the earthquake force on the water because of this assumption is probably within 1%.

Horizontal Earthquake

The inertial force on the concrete should be applied at the centre of gravity of the mass regardless of the shape of the cross section. For dams with vertical or sloping upstream faces, the increase in water pressure P_e at any elevation due to horizontal earthquake is given by the following equation:

$$P_e = C\lambda wh$$

Where C = a dimensionless coefficient giving the distribution and magnitude of pressure

λ = earthquake intensity = S_a/g

w = unit weight of water, pounds per cubic foot

h = total depth of reservoir at section being considered

Values of C for various degrees of slope and relations of y/h may be obtained from Figure 27.5. It has been shown analytically that the total horizontal force, V_e , above any elevation y distance below the reservoir surface, and the total overturning moment, M_e , above that elevation are:

$$V_e = 0.726P_e y$$

$$M_e = 0.299P_e y^2$$

For dams with a combination of vertical and sloping face, consider vertical face throughout if more than half the height is vertical and sloping face otherwise on a sloping line connecting the point of intersection of the upstream face of the dam and reservoir surface with the point of intersection of the upstream face of the dam and foundation.

Vertical Earthquake

On sloping faces of dams the weight of the water above the slope should be modified by the appropriate acceleration factor. The weight of the concrete also should be modified by this acceleration factor.

Inertia and hydrodynamic forces act on dams during earthquakes besides the normal forces. Inertial force acts in direction opposite to the seismic force. Zanger's method is applied to find the hydrodynamic forces, which assumes rigid body movement of dam and incompressibility of water. The dynamic behaviour of dam-reservoir system is evaluated as two uncoupled systems ignoring small interaction effects.

Seismic coefficient method is used for dams up to 60 m in height. The horizontal acceleration is assumed to have the shape of an inverted triangle with top value equal to 1.5 times the horizontal seismic coefficient. Response spectrum method is used for dams above 60 m in height.

Vertical acceleration is assumed to have a shape of an inverted triangle with top value equal to half the horizontal seismic acceleration.

Y/h = Distance below surface / Total Depth

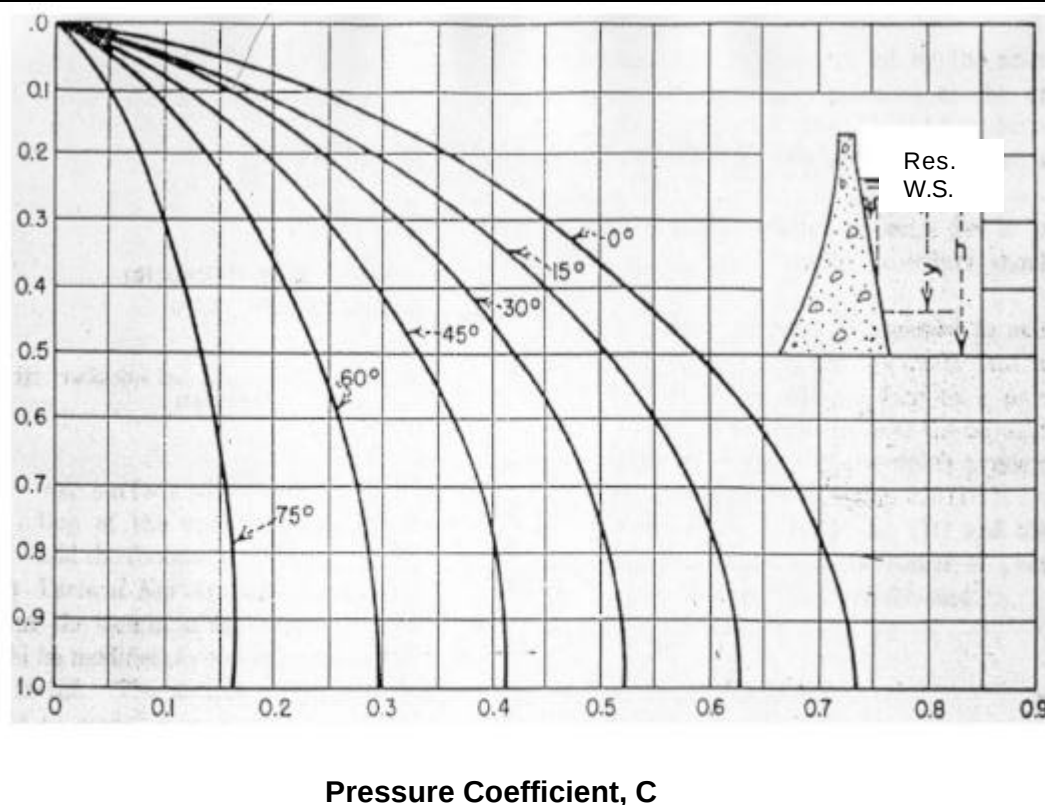


Figure 27.5 Seismic Pressure Coefficients for Gravity Dams

27.13.6 Design of Earth and Rock Fill Dams and Embankments

The determination of potential earthquake activity within a given region can be made from a seismic risk map or by consultation with a seismologist or engineering geologist. If the dam site lies within a zone of high seismic activity the advice of an experienced dam designer should be obtained.

The use of large downstream zones of quarried rock compacted in thin layers (decked rock fill dam) provides maximum stability against seismic shaking and maximum resistance to the flow of large quantities of water through the section should cracking occur. The rock fill should be a well-graded and angular rock fragment of high strength and durability. To accommodate the larger downstream zones, it is recommended to flatten the downstream slope of the decked rock fill to 1.7:1. The upstream slope of the embankment should also be flattened where conservative designs are warranted.

The foundation of the dam should be preferably on firm rock, however, free-draining foundations may be used if their degree of compaction is similar to the rock fill material and a competent dam designer approves them. Trench type foundation cut-offs are also recommended. In addition, it is desirable to provide a thicker zone beneath the rock zone and to reduce the lift thickness to a maximum of 0.9 m. Other precautions are to use a thicker membrane on the upstream slope or to reinforce concrete membranes in both faces.

No exact rules for design within the earthquake regions exist and an authority in this field should be consulted when serious seismic conditions exist.

The factor of safety concept in earth and rock fill dams and embankments does not truly reflect the safety of structure. Dynamic analysis should be carried out for determination of stress, strain and displacement at various points due to earthquake and to check with strength properties of

various materials. The dynamic analysis requires strength characteristics of materials under dynamic conditions that are not available and therefore, seismic coefficient method may be applied with precautions to ensure safety. The following procedure should be followed:

- Determine fundamental period
- Determine spectral acceleration from Figure 27.4
- Determine design seismic coefficient
- Carry out slope stability analysis using seismic forces.

For special structures, important factors to be considered are:

- Spillways, their connections with the main dam, spillway lining, etc.
- Contingent drainage provisions in case of dam failure and emptying of the reservoir to facilitate repairs.
- Abutments of the dam, and
- Other appurtenant structures connected to the main dam.

27.13.7 Design of Embankment Dams

- Pseudo static stability analysis is recommended to determine factor of safety of upstream and downstream slopes that account for height of dam, average material properties and response characteristics.
- Limitation of pseudo static analysis is that only shear forces considered but duration of action not considered. The factor of safety greater than unity does not necessarily mean the structure is safe and undesirably large deformation can result. The deformation may include settlement / slumping of the crest, flattening of the slopes, minor or major longitudinal cracks or minor or major transverse cracks.
- Possible measures include
 - Larger freeboard to account for slumping of crest
 - Prevention of concentrated leakage to account for cracks.

A proper and rational method of arriving at the seismic stability of embankment dams is to ascertain the deformation of the dam when subjected to the earthquake forces. The following steps may be used:

- Determining the yield acceleration of the structure considering the effective stress parameters and computing the displacements on the assumption that the ruptured mass is similar to a rigid mass resting on an inclined plane.
- Determining average stress conditions along potential slip circles prior to and during the earthquake and ascertaining the strains these stresses will cause on representative soil samples tested in the laboratory. Summing up the strains to obtain loss of freeboard has also been attempted.
- Use of averages from a parametric study to obtain the order of deformation.

27.13.8 Design of Retaining Walls

The stability of retaining wall is calculated in terms of factors of safety against base sliding, against overturning and against failure of foundation. Prediction of displacement of retaining wall under earthquake loading condition is not required. The active earth pressure of soil is increased while the passive earth pressure is decreased due to earthquake.

Early Approach

For design of retaining wall a reduction in friction angle is made as follows in the early approach:

$$\phi_{\text{dyn}} = \phi - \tan^{-1} \alpha_h \quad \text{where only horizontal seismic action is considered.}$$

$$\phi_{dyn} = \phi - \tan^{-1} \alpha_h / \alpha_v \quad \text{where both horizontal and vertical seismic actions are considered}$$

Modified Coulomb's Approach

A more rational approach to deal with seismic action is to use a formula that modifies Coulomb's classical formula. The modified formula for active and passive forces under seismic conditions is as follows:

The earthquake forces applied in retaining walls are:

- Horizontal force equal to horizontal seismic coefficient times the weight of the wedge away from backfill for active condition applied at mid height of wall and towards backfill for passive conditions applied at $2/3$ the height from base.
- Vertical force equal to the vertical seismic coefficient times the weight of the wedge in upward direction for sliding, overturning and stability and downward direction for toe and heel pressures.
- The dynamic increment in active and passive pressures due to uniform surcharge should be applied at $2/3$ the height from base.
- Under moist conditions, the value of $\tan \lambda = w_s \cdot \alpha_h / (w_s - 1) / (1 \pm \alpha_v)$ where λ inclination of resultant when seismic forces are considered from that when seismic forces are not considered.
- The partial safety factors may be decreased when seismic action is considered.

27.13.9 Design of Educational Buildings

The design of educational buildings shall comply with the provisions laid in *UNESCO Educational Building Report 13 Protection of Educational Buildings against Earthquakes*.

General principles of earthquake resistant design of educational buildings are as follows:

- The site must be selected in firm and stable ground avoiding slides, rock falls, rupture zones and areas with liquefaction and densification potential.
- Simple rectangular buildings are the most desirable, the length of the block being not more than about three times the width.
- Symmetrical buildings in plan and elevation are better than asymmetrical buildings.
- Large projections should be avoided. Parapets and cantilever projections should be reinforced and adequately anchored.
- Long rooms (> 9 m) should be subdivided into boxlike enclosures or buttressed.
- Openings must be as small as possible and must be symmetrical.
- Highly suitable materials such as steel, wood, RCC should be preferred. Block masonry, RBC, reinforced adobe etc. are moderately suitable.
- Construction materials should conform to appropriate specifications.
- Proper mortar should be used in construction filling all horizontal and vertical joints. Masonry joints must be staggered. Adobe (low strength masonry) should be preferably avoided.
- Joints in wood elements should be tight, nailed or bolted and covered with steel straps.
- Stone masonry walls must have appropriate mortar filling at hearting and use of bond stone or "through" elements is a must.
- The height of school buildings should be restricted to two stories but residential blocks may have an additional attic.
- Seasoned timber should be used for building construction.
- Wooden buildings must have bracing to resist the lateral load due to earthquakes.

- Timber buildings must be rigidly fixed into plinth masonry or concrete foundation.
- Trusses must be held to masonry walls by adequate bolts.
- Both horizontal and vertical reinforcing is required in walls.
- End panel of jack arch must be tied properly between wall and beam.
- Any adobe construction should be strengthened using pitched roof, bracing, horizontal bands, vertical buttresses etc.

27.13.10 Design of Earthen Buildings

The design of earthen building not exceeding one storey in height plus an additional attic floor shall comply with the *NBC 204:1994 Guidelines for Earthquake Resistant Building Construction: Earthen Buildings*.

- General requirements for earthquake resistant design and construction of earthen buildings are as follows:
- The construction site must be stable and safe enough to withstand foundation pressures. It must be free from ruptures, slides, and subsidence.
- The form of building must be regular, rectangular and symmetrical.
- The foundation must be suitable enough to transfer the dead, live and seismic loads.
- The building must be subdivided into box like units either with partitions or buttresses.
- The wall elements must be braced with vertical reinforcement, horizontal bands, diagonal bracing or lateral restraints.
- The height of building should not exceed single storey plus an attic.
- Adequate bond stones should be provided at walls and corners.
- The opening size and location must be small and symmetrical to prevent excessive deformation or failure during an earthquake.

27.14 Recommendations for Earthquake Resistant Design

General recommendations for earthquake resistant design of various civil engineering structures are listed in Table 27.8.

Table 27.8 Summary of Recommended Methods for Earthquake Resistant Design

Structure category	Recommended method
Simple building structures with height greater than 40 m	• For preliminary design, modal analysis using response spectrum method • For detailed design, detailed dynamic analysis either modal analysis or time history analysis based on expected ground motion
Simple building structure with height less than 40 m	• Modal analysis using response spectrum method is preferred • Use of seismic coefficient method is also permitted
Design of masonry buildings or earthen buildings	• Analytical design and safety verification is not mandatory • Precautionary measures to be taken for detailing
Buildings with irregular shape and/or irregular distribution of mass and stiffeners	• Modal analysis using response spectrum

Structure category	Recommended method
Retaining walls with height less than 6 m	• Earliest Approach (static analysis) using reduced dynamic soil parameters
Retaining walls with height greater than 6 m	• Modified Coulomb's Theory
Large embankment dams, height greater than 15 m	• Finite Element Method
Small embankment dams, height less than 15 m	• Static analysis using reduced dynamic soil parameters
Gravity dam with height greater than 60 m	• Response spectrum method
Gravity dam with height less than 60 m	• Seismic coefficient method along with Zanger's method
Slab culvert, pipe culvert, box culvert	• No seismic design required
RCC, plate girder and truss bridges (minor and medium)	• Seismic coefficient method
Special bridges span greater than 60 m or pier height more than 30 m	• Modal response spectrum method
Masonry / PCC arch bridges	• Not recommended for spans more than 10 m nor for multiple spans
Stack-like structures	• Designed as cantilever elements
Design of tower supported tanks	• Seismic coefficient method with 0.75 times reduction or • Response spectrum method • Only impulsive hydrodynamic pressures to be considered. • Convective pressures may be neglected.

27.15 Specific Guidelines

The following specific guidelines are recommended to mitigate the risk of damage of structures due to earthquake:

Design	• The structure should be simple in shape and regular in form. • Capacity design procedures should be followed where required. • Connection detailing should be made as per suggested measures in pertinent codes. • Specific restrictions on height and characteristics of structures considering local seismic activity, importance, ground conditions, city planning and environmental planning. • Adequate structural model and influence of soil deformability and non-structural members. • No changes should be permitted during construction and subsequent life of the structure unless otherwise approved by a structural engineer. • The structure must be used as per design brief.
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Foundation	• As far as possible, uniform transfer of load to foundation should be attempted. • Single type of foundation should be provided for entire dynamically dependent unit.
Quality System Plan	• Design documents should be well documented and should clearly show: • Size, details and characteristics of structural materials • Characteristics of special devices • Quality control provisions • Identification of special structural elements that need: ◦ To be checked ◦ Checking method to be specified • For high seismic areas and structures having special importance, additional procedures for formal quality system plans during design, construction and subsequent use should be elaborated