

## Preface

This Draft Nepal Standard was prepared during 1993 as part of a project to prepare a draft National Building Code for Nepal.

In 1988 the Ministry of Housing and Physical Planning (MHPP), conscious of the growing needs of Nepal's urban and shelter sectors, requested technical assistance from the United Nations Development Programme and their executing agency, United Nations Centre for Human Settlements (UNCHS).

A programme of Policy and Technical Support was set up within the Ministry (UNDP Project NEP/88/054) and a number of activities have been undertaken within this framework.

The 1988 earthquake in Nepal, and the resulting deaths and damage to both housing and schools, again drew attention to the need for changes and improvement in current building construction and design methods.

Until now, Nepal has not had any regulations or documents of its own setting out either requirements or good practice for achieving satisfactory strength in buildings.

In late 1991 the MHPP and UNCHS requested proposals for the development of such regulations and documents from international organisations in response to terms of reference prepared by a panel of experts.

This document has been prepared by the subcontractor's team working within the Department of Building, the team including members of the Department and the MHPP. As part of the proposed management and implementation strategy, it has been prepared so as to conform with the general presentation requirements of the Nepal Bureau of Standards and Metrology.

The subproject has been undertaken under the aegis of an Advisory Panel to the MHPP.

The Advisory Panel consisted of :

Mr. UB Malla, Joint Secretary, MHPP	Chairman
Director General, Department of Building	
(Mr. LR Upadhyay)	Member
Mr. AR Pant, Under Secretary, MHPP	Member
Director General, Department of Mines & Geology	
(Mr. PL Shrestha)	Member
Director General, Nepal Bureau of Standards & Metrology	
(Mr. PB Manandhar)	Member
Dean, Institute of Engineering, Tribhuvan University	
(Dr. SB Mathe)	Member
Project Chief, Earthquake Areas Rehabilitation & Reconstruction Project	Member
President, Nepal Engineers Association	Member
Law Officer, MHPP (Mr. RB Dange)	Member
Representative, Society of Consulting Architectural & Engineering Firms (SCAEF)	Member

Representative, Society of Nepalese Architects (SONA)  
Deputy Director General, Department of Building,  
(Mr. JP Pradhan)

Member

Member-Secretary

The Subcontractor was BECA WORLEY INTERNATIONAL CONSULTANTS LTD. of New Zealand in conjunction with subconsultants who included :

Golder Associates Ltd., Canada  
SILT Consultants P. Ltd., Nepal  
TAEC Consult (P.) Ltd., Nepal  
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## **0 Foreword**

### **0.1 Design Procedure**

This Standard provides minimum requirements for the seismic design of structures which are within the scope of this Standard as defined in 1.

### **0.2 Related Codes**

The requirements of this section of the Nepal Building Code shall be applied in conjunction with, IS 4326 - 1976 Code of Practice for Earthquake Resistant Design and Construction of Buildings.

Where conflict exists between any requirements of this Standard and IS 4326, the requirements of this Standard shall be taken.

### **0.3 Commentary**

A commentary, which explains the reasons for many of the clauses in this Standard, forms an accompanying volume to this document. This Standard should always be read in association with the Commentary.

## 1 Scope

This standard sets down requirements for the general structural design and seismic design loadings for structures within any of the following categories :

- (a) All buildings having a floor area greater than 20 square metres.
- (b) Any building with a height greater than five metres.
- (c) All masonry or concrete walls greater than 1.5 metres in height.
- (d) Elevated tanks of up to 200 cubic metres capacity. Larger tanks than this should be the subject of a special study.
- (e) All buildings to which the general public have access.

The requirements are not intended to apply to :

- (a) Unusual buildings or structures (eg, those with unusual configurations or risk - such as nuclear power stations, etc).
- (b) Civil engineering works (eg, bridges, dams, earth structures, etc).
- (c) Buildings or structures greater than 90 m in height.



## 2 Interpretation

### 2.1 General

2.1.1 In this Standard the word "shall" indicates a requirement that must be adopted in order to comply with the Standard, while the word "should" indicates recommended practice.

2.1.2 Commentary clauses (in Part 2) are prefaced by the letter C and the number of the appropriate clause subject to comment.

### 2.2 Terminology

In this standard, unless inconsistent with the context :

#### **ANALYSIS METHODS :**

**SEISMIC COEFFICIENT METHOD** means a method of analysis using static loads to simulate the effects of earthquake ground motion.

**MODAL RESPONSE SPECTRUM METHOD** means a method of dynamic analysis in which a given earthquake design spectrum is applied to a mathematical model of the structure and the response of several modes are determined, and combined.

**DEAD LOAD** means the weight of all permanent components of a building including walls, partitions, columns, floors, roofs, finishes and fixed plant and fittings that are an integral part of the structure.

**DESIGN** means the use of rational computational or experimental methods in accordance with the established principles of structural mechanics.

**DIAPHRAGM** means a member composed of a web (such as a floor or roof slab), or a truss which distributes forces to the horizontal load resisting system.

**DUCTILITY** means the ability of the building or member to undergo repeated and reversing inelastic deflection beyond the point of first yield while maintaining a substantial proportion of its initial maximum load carrying capacity.

**ELEMENTS** includes primary and secondary elements :

**PRIMARY ELEMENTS** means elements forming part of the basic load resisting structure, such as beams, columns, diaphragms, or shear walls necessary for the building's survival when subjected to the specified loadings.

**SECONDARY ELEMENTS** means elements such as intermediate or secondary beams, partition walls, panels, or veneers not necessary for the survival of the building as a whole but which may be subject to stresses due

to load applied directly to them or to stresses induced by the deformations of the primary elements.

**FRAME** means a system composed of interconnected members functioning as a complete self-contained unit with or without the aid of horizontal diaphragms or floor bracing systems.

**MOMENT RESISTING FRAME** means a load carrying frame in which the members and joints are capable of resisting horizontal loads through bending moments.

**HORIZONTAL LOAD RESISTING SYSTEM** means that part of the structural system to which the horizontal loads prescribed by this Standard are assigned.

**LEVEL OF LATERAL RESTRAINT** is the level at which the ground motion of the earthquake is transmitted to the structure by interaction between the foundation materials and the foundation elements by friction and bearing.

**LIVE LOAD** means the load assumed or known to result from the occupancy or use of a building and includes the loads on floors, loads on roofs other than wind, loads on balustrades and loads from movable goods, machinery, and plant that are not an integral part of the building.

**SET BACK** means any offset horizontally in from the plane of an exterior wall of a structure.

**SHEAR WALL** means a wall of any material required to resist horizontal loads through the transfer of shear forces.

**STOREY** means the space between two adjacent floors or platform levels.

### 2.3 Symbols

Symbols used in the Standard shall have the following meanings :

$b$	maximum horizontal dimension of the building at the particular level measured perpendicular to the direction of loading
$C$	basic seismic coefficient for the seismic coefficient method
$C(T_i)$	ordinate of the basic response spectrum for translational period $T_i$
$C_d$	design horizontal seismic force coefficient
$C_d(T_i)$	ordinate of the design spectrum for translational period $T_i$
$DL$	design dead load
$D'$	overall length of the building at the base in the direction under consideration (m)
$d_i$	horizontal displacement of the centre of mass at level $i$ under the horizontal seismic loading specified by this Standard (ie $F_i$ )
$E$	design earthquake load
$e_d$	design eccentricity of the seismic load at a particular level
$e_c$	computed eccentricity of the centre of mass from the centre of rigidity
$F_i$	horizontal seismic force applied at a level designated as $i$
$F_p$	design seismic force for elements and components designed in accordance with 8
$g$	acceleration due to gravity. To be taken as $9.81 \text{ m/s}^2$
$H$	height to the top of the main portion of the building or the eaves of the building (m)
$h_i$	height to the level designated as $i$ from the level of lateral restraint
$I$	importance factor for the building

$K$	structural performance factor appropriate for the particular structural type
$K_p$	component seismic performance coefficient
$LL$	design live load
$P$	structural response factor
$S$	modal combination factor
$SL$	design snow, or ice load
$T_1$	natural period of vibration of the first mode of the structure
$T_i$	translational period of vibration for mode $i$
$V$	total horizontal seismic base shear
$W_i$	proportion of $W_t$ contributed by level $i$
$W_p$	weight of the element, component or item of equipment
$W_t$	total of the gravity loads $W_i$ above the level of lateral restraint
$Z$	seismic zoning factor

### **3 General Principles of Ductile Seismic Design and Detailing**

#### **3.1 Structural System**

Buildings shall be designed with a clearly defined (identifiable) load path, or paths, to transfer the inertial forces generated in an earthquake to the supporting soils.

#### **3.2 Ductility**

Buildings and all their seismic load resisting elements should be designed and detailed to perform in a ductile manner.

Satisfactory ductility can be assumed if the structure will withstand, without significant loss of vertical and/or lateral load carrying capacity, the lateral deflections specified in 9.1 applied through several reversals (cycles).

For the purposes of this Standard the above general requirement may be assumed to be adequately met if the specific requirements of Table 8.2 are complied with.

#### **3.3 Energy Dissipation**

In addition to the provision of adequate ductility, structures should also be designed to prevent the concentration of the demand for ductility in a few members, except where special provisions are made to increase the ductility available in those members.

The demand for ductility should be spread throughout the structure so that the earthquake induced energy is dissipated uniformly.

For the purpose of this Standard the above general requirements may be assumed to be adequately met if the specific requirements of Table 8.2 are complied with.

#### **3.4 Symmetry**

The seismic load resisting elements of a structure should be located, as nearly as practicable, symmetrically about the centre of mass of the structure.

Re-entrant angles in the plan shape of a structure should be avoided.

#### **3.5 Uniformity of Storey Stiffness**

Significant changes in the stiffness over the height of the building should be avoided.

#### **3.6 Floor Diaphragms and Bracing**

The horizontal bracing system or diaphragm at each floor shall be designed to distribute forces to the individual elements of the horizontal load resisting system in proportion to their rigidities.

### **3.7 Interconnection of Floors and Roof**

Concrete and masonry walls shall be anchored to all floors or roofs that are required to provide them with horizontal support or stability. Such anchorage shall be designed for the loads determined from 12, or a minimum load of 3 kN per metre of wall, whichever is greater. Spacing of such anchors shall not exceed one metre unless the wall is designed to span between them.

Such connections to walls shall also comply with the requirements of 12.2.

### **3.8 Interconnection of Foundations**

Individual foundations of a building shall be interconnected in two directions, generally at right angles, by members designed for an axial tension and compression equal to 10 % of the maximum vertical load on either foundation under seismic conditions.

If the axial load on one of the interconnected foundations is less than 20 % of that on the other, the design axial load in the interconnecting elements shall be taken as 10 % of the average vertical load on the two foundations under seismic conditions.

## **4 Design Methods & Load Combinations**

### **4.1 General**

Design for earthquake actions shall be in accordance with either :

- (a) The Working Stress Method (elastic method), or
- (b) The Limit State Method

provided that reinforced concrete design shall be in accordance with the Limit State Method unless specifically noted otherwise.

### **4.2 Increase in Allowable Material Stresses for the Working Stress Method**

Whenever earthquake forces are considered along with other design forces, the allowable material stresses may be increased by one third but shall not exceed the following limits :

- (a) Steels with a definite yield stress; the yield stress
- (b) Steels without a definite yield stress; 80 percent of the ultimate strength or the 0.2 percent proof stress whichever is smaller.

#### 4.3 Increase in Allowable Soil Bearing Pressure

Whenever earthquake forces are considered along with other design forces, the allowable soil bearing pressures may be increased by up to 50 percent.

#### 4.4 Design Load Combinations for the Working Stress Method

The design loads including earthquake for the Working Stress Method shall be not less than whichever of the following load combinations gives the greatest effect

$$DL + LL + E$$

$$0.7 DL + E$$

$$DL + SL + E$$

#### 4.5 Design Load Combinations for the Limit State Method

The design loads including earthquake for the Limit State Method shall be not less than whichever of the following load combination gives the greatest effect :

$$DL + 1.3 LL + 1.25 E$$

$$0.9 DL + 1.25 E$$

$$DL + 1.3 SL + 1.25 E$$

### 5 Methods of Analysis

#### 5.1 General

Analysis for the design earthquake actions shall be in accordance with one of the following methods :

- (a) The Seismic Coefficient Method as outlined in 10, or,
- (b) The Modal Response Spectrum method as outlined in 11.

Note : Analysis using numerical integration time history procedures is not covered by this Standard.

#### 5.2 Selection of Method of Analysis

For structures of up to 40 m in height the Seismic Coefficient Method may be used. For all other structures the Modal Response Spectrum Method shall be used.

The Modal Spectrum Method should be used for :

- (a) Buildings with irregular configurations
- (b) Buildings with abrupt changes in lateral resistance
- (c) Buildings with abrupt changes in lateral stiffness with height
- (d) Buildings with unusual shape, size or importance.

## 6 Seismic Weight

The seismic weight at each level,  $W_i$ , shall be taken as the sum of the dead loads and the seismic live loads between the mid-heights of adjacent storeys.

The seismic live load shall be taken as a percentage of the design live load as given in Table 6.1.

Design Live Load	Percentage of Design Live Load
Up to 3 kPa	25
Above 3 kPa and for vehicle garages	50
For Roofs	NIL

Table 6.1

The seismic weight for roofs shall include allowance for ice if appropriate.

## 7 Periods of Vibration

7.1 The periods of vibration,  $T_i$ , shall be established from properly substantiated data, or computation, or both.

7.2 Where the Seismic Coefficient Method is used, the fundamental translation period in the direction under consideration,  $T_1$ , shall be determined from :

$$T_1 = 2 \pi \sqrt{\sum W_i d_i^2 / g \sum F_i d_i} \quad 7.1$$

where  $d_i$  may be calculated ignoring the effects of torsion.



7.3 For the purposes of initial member sizing, the following approximate formulae for  $T_i$  may be used :

(a) For framed structures with no rigid elements limiting the deflection :

$$T_i = 0.085 H^{1/4} \text{ for steel frames} \quad 7.2$$

$$T_i = 0.06 H^{1/4} \text{ for concrete frames} \quad 7.3$$

(b) For other structures :

$$T_i = \frac{0.09 H}{\sqrt{D'}} \quad 7.4$$

If  $T_i$  calculated using these equations is greater than 120 percent of that finally calculated using Equation 7.1, the seismic forces shall be re-assessed.

## 8 Seismic Design Actions

### 8.1 Design Spectra and Lateral Force Coefficients

#### 8.1.1 Design Horizontal Seismic Coefficient for the Seismic Coefficient Method

The design horizontal seismic force coefficient,  $C_d$  shall be taken as :

$$C_d = CZIK \quad 8.1$$

Where  $C$  is the basic seismic coefficient for the fundamental translational period in the direction under consideration.

#### 8.1.2 Design Spectrum for the Modal Response Spectrum Method

The design spectrum,  $C_d(T_i)$ , shall be taken as :

$$C_d(T_i) = C(T_i) ZIK \quad 8.2$$

Where  $C(T_i)$  is the ordinate of the basic response spectrum for translational period,  $T_i$ .

#### 8.1.3 Basic Seismic Coefficient

The basic seismic coefficient,  $C$ , shall be determined from Figure 8.1 for the appropriate site subsoil category using the fundamental structural period determined in accordance with 7.2 for the direction under consideration.

#### 8.1.4 Basic Response Spectrum

The basic spectrum,  $C(T)$ , shall be determined from Figure 8.1 for the appropriate site subsoil category, and period,  $T$ .

#### 8.1.5 Site Subsoil Category

The site shall be classified into one of the following site subsoil categories :

Type I      Rock or Stiff Soil Sites.

Sites with bedrock, including weathered rock with an unconfined compression strength greater than 500 kPa, overlain by less than 20 m of :

- (a) very stiff cohesive material with an unconfined compression strength greater than 100 kPa, or
- (b) very dense cohesionless material with  $N > 30$ , where  $N$  is the standard penetration (SPT) value.

Such sites will typically have a low amplitude natural period of less than 0.2 s.

Type II      Medium Soil Sites

Sites not described as either Type I or Type III

Type III      Soft Soil Sites

Sites where the depth of soil of a particular type exceeds the following values :

a) Cohesive Soils

Cohesive Soil Classification	Representative undrained shear strength (kPa)	Minimum Depth of Soil (m)
Soft	12.5 - 25	20
Firm	25 - 50	25
Stiff	50 - 100	40
Very Stiff	100 - 200	60

contd.../

b) Cohesionless Soils

Cohesionless Soils Classification	Representative SPT values (N)	Minimum Depth of Soil (m)
Loose	4 - 10	40
Medium Dense	10 - 30	45
Dense	30 - 50	55
Very Dense	> 50	60
Gravels	> 30	100

Such sites will typically have a low amplitude natural period greater than 0.6 s.

**8.1.6 Seismic Zoning Factor**

The seismic zoning factor,  $Z$ , shall be obtained from Figure 8.2 for the appropriate location.

**8.1.7 Importance Factor**

The importance factor,  $I$ , for the structure shall be obtained from Table 8.1.

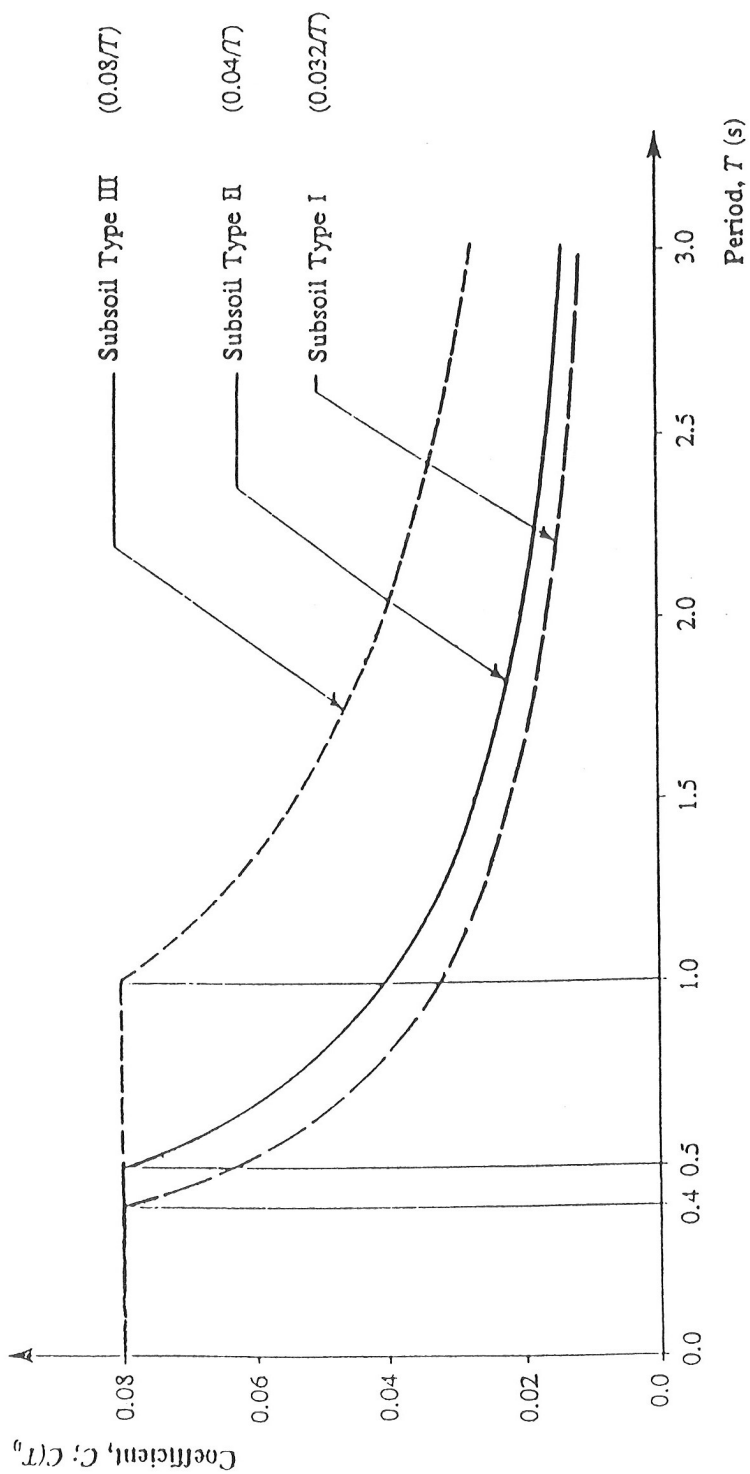
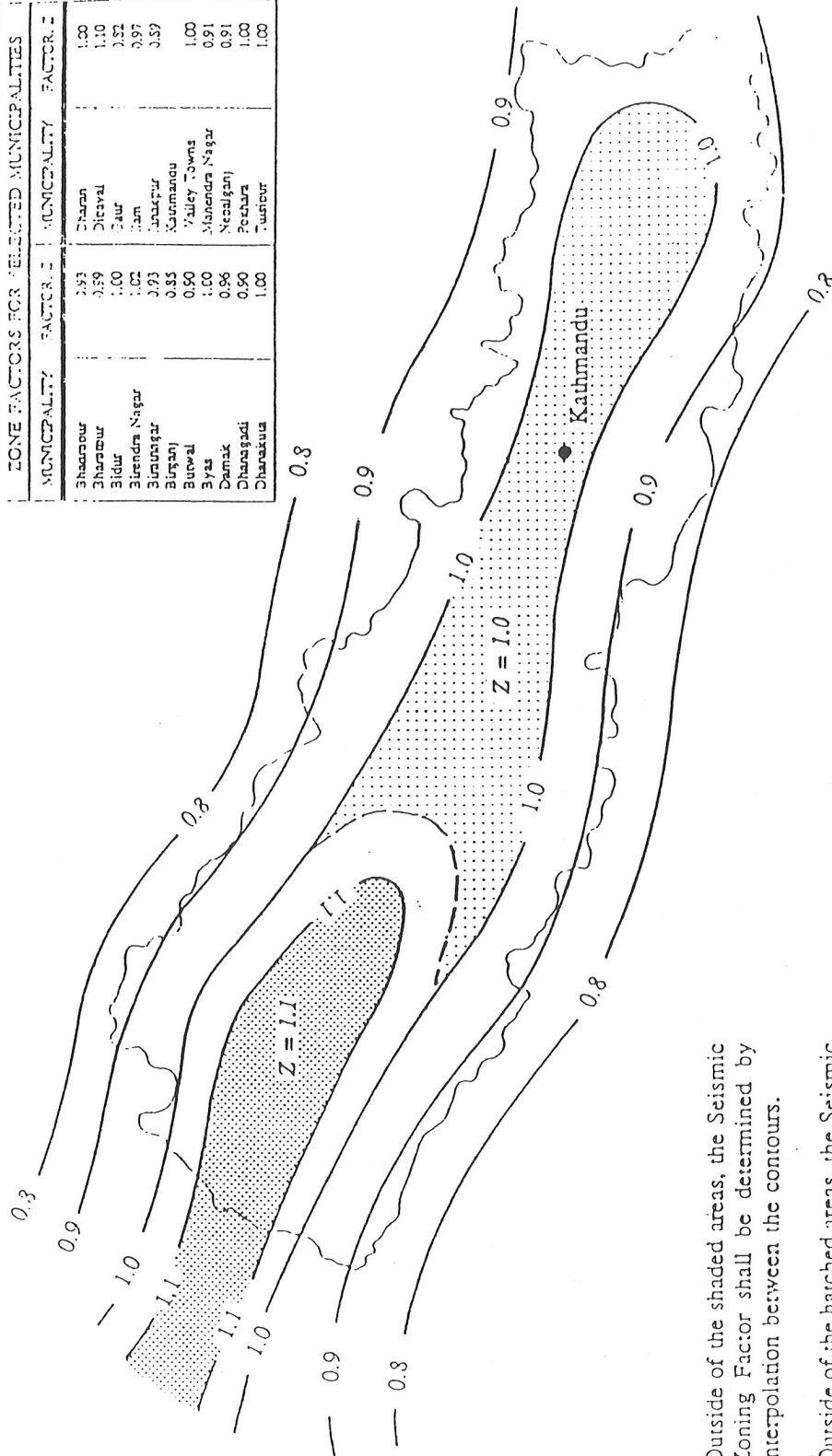


Figure 8.1 : BASIC SEISMIC COEFFICIENT,  $C$   
BASIC RESPONSE SPECTRUM,  $C(T)$

ZONE FACTORS FOR SELECTED MUNICIPALITIES				
MUNICIPALITY		FACTOR, Z	MUNICIPALITY	FACTOR, Z
Bhadrapur		0.93	Charan	1.00
Bharanpur		0.89	Dicaval	1.10
Bidur		1.00	Daur	0.82
Birendra Nagar		1.02	Jan	0.97
Birgaun		0.93	Katipur	0.89
Birgaun		0.85	Katmandu	
Burelal		0.90	Valley Towns	1.00
Byas		1.00	Manendra Nagar	0.91
Dumak		0.96	Nawalpur	0.91
Dhanagadi		0.90	Pokhara	1.00
Dhanakuta		1.00	Tulsipur	1.00



Outside of the shaded areas, the Seismic Zoning Factor shall be determined by interpolation between the contours.

Outside of the hatched areas, the Seismic Zoning Factor shall be determined by interpolation between the contours.

Figure 8.2 : SEISMIC ZONING FACTOR, Z

	Type of Building	Importance Factor <i>I</i>
(a)	Monumental Buildings	1.5
(b)	Essential facilities that should remain functional after an earthquake	1.5
	Examples of these facilities would be :	
	Hospitals and other medical facilities	
	Fire and Police stations	
	Emergency vehicle shelters/garages	
	Food storage structures	
	Emergency relief stores	
	Power stations (including standby power-generating equipment for essential facilities)	
	Water works and water towers	
	Radio and television facilities	
	Telephone exchanges and transmission facilities	
	Offices and residential quarters for senior personnel required for central and district-level rescue and relief operations (ministers, secretaries, police and army chiefs; CDO, LDO and DDC chairmen, district-level army and police chiefs	
	Places of assembly (schools, colleges, cinemas, convention halls, temples, dharmshalas).	
(c)	Distribution facilities for gas or petroleum products in urban areas.	2.0
(d)	Structures for the support or containment of dangerous substances (such as acids, toxic substances, etc.).	2.0
(e)	Other structures	1.0

**Table 8.1 : Importance Factor *I***

#### **8.1.8 Structural Performance Factor**

The minimum permissible value of the structural performance factor, *K*, and associated detailing requirements shall be as given in Table 8.2.

In order to qualify for the *K* factors given in Table 8.2, the chosen structural type shall meet the minimum detailing requirements shown.

The structural type may be different in each of two directions in a building and in that case the appropriate value for *K* shall be selected for each direction.

When more than one structural type is used in the structure, for the direction under consideration, the structural performance factor for the element providing the majority of the seismic load resistance shall be applied provided that the elements of the other structural types have the ability to accept the resulting deformations.

Item	Structural Type	Minimum Detailing Requirements	Structural Performance Factor $K$
1.(a)	Ductile moment-resisting frame	Must comply with the detailing for ductility requirements of IS 4326 and, for steel frames, the additional requirements of NBC 111-94	1.0
(b)	Frame as in 1(a) with reinforced concrete shear walls	For frames : as for 1(a). Reinforced concrete shear walls must comply with appropriate <sup>3</sup> detailing for ductility requirements.	1.0 <sup>1</sup>
2.(a)	Frame as in 1(a) with either steel bracing members detailed for ductility or reinforced concrete infill panels	For frames : as for 1(a). Steel bracing members must comply with the detailing for ductility requirements of NBC 111-94. Reinforced concrete infill panels must comply with the detailing requirements of NBC 109-94.	1.5 <sup>1,2</sup>
(b)	Frame as in 1(a) with masonry infills	Must comply with the detailing for ductility requirements of: IS 4326	2.0 <sup>1,2</sup>
3.	Diagonally-braced steel frame with ductile bracing acting in tension only	Must comply with the detailing for ductility requirements of Nepal Steel Construction Standard	2.0
4.	Cable-stayed chimneys	Appropriate materials Standard	3.0
5.	Structures of minimal ductility including reinforced concrete frames not covered by 1 or 2 above, and masonry bearing wall structures.	Appropriate materials Standard	4.0

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Table 8.2 :  
Structural Performance Factor  $K$  and other Design Requirements for Horizontal Load-Resisting Systems of Buildings and other Structures

Table 8.2 continued

NOTES :

1. *These factors shall apply only if the steel bracing members, the shear walls and/or the infill panels are taken into consideration in both the stiffness and lateral strength calculations.*
2. *These factors shall apply only if the frame acting alone is capable of resisting at least 25 percent of the design seismic forces.*
3. *NBC 110-94 does not make specific reference to the detailing of ductile shear walls. If such walls are to be used, the designer is referred to the following references for guidance on appropriate detailing :*

*Park, R. and Paulay, T., Reinforced Concrete Structures, Wiley, 1975.*

*New Zealand Standard NZS 3101:1982, Code of Practice for the Design of Concrete Structures (under revision), SANZ, Wellington.*

## 8.2 Direction of Forces and Design Eccentricity

### 8.2.1 Direction of Forces

For structures with seismic resisting systems located along two perpendicular directions, the specified forces may be assumed to act separately along each of these two horizontal directions. For other buildings, different directions of application of the specified forces shall be considered so as to produce the most unfavourable effect in any structural element.

### 8.2.2 Design Eccentricity

The design eccentricity,  $e_d$ , shall be determined as follows :

- (a) If  $e_c$  is less than  $0.1 b$  and the building is 4 storeys or less in height :

$e_d$  may be taken as equal to 0

- (b) If  $e_c$  is less than  $0.3 b$  and 8.2.2(a) does not apply;

$$e_d = e_c + 0.1 b \quad \text{or} \quad e_d = e_c - 0.1 b \quad 8.3$$

whichever is the most severe for the element under consideration.

- (c) If  $e_c$  is greater than  $0.3 b$ , the structure should be analyzed 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.



### **8.3 Vertical Seismic Forces**

The effect of the vertical components of seismic motion need not be considered in design of a structure except as specified in 12. Where consideration of vertical seismic forces is required, the design vertical seismic coefficient shall be taken as one half of the horizontal seismic coefficient given in 8.1.1.

## **9 Deformation Due to Earthquake Forces**

### **9.1 Derivation of Design Lateral Deformations**

The design lateral deformations shall be taken as the deformations resulting from the application of the forces or design spectrum as specified in 10 or 11 respectively, multiplied by the factor  $S/K$ .

### **9.2 Building Separations**

#### **9.2.1 To Boundaries**

Above ground level, each building of greater than three storeys shall have a separation from the boundary, except adjacent to a designed street or public way, of not less than the design lateral deflection determined in accordance with 9.1 or  $0.002 h_i$  or 25 mm which ever is the greater.

#### **9.2.2 Within Site**

Parts of buildings or buildings on the same site which are not designed to act as an integral unit shall be separated from each other by a distance of not less than the sum of the design lateral deflections determined in accordance with 9.1 or  $0.004 h_i$  or 50 mm which ever is the greater.

#### **9.2.3 Separation Space Width**

Separation spaces shall be detailed and constructed to remain clear of debris and other obstructions. The width of such spaces shall allow for all constructional tolerances.

### **9.3 Inter-Storey Deflections**

The ratio of the inter-storey deflection to the corresponding storey height shall not exceed 0.010 nor shall the inter-storey deflection exceed 60 mm (refer also to 12.6.2).

## 10 Seismic Coefficient Method

### 10.1 Horizontal Seismic Base Shear

10.1.1 The horizontal seismic shear force acting at the base of the structure, in the direction being considered, shall be :

$$V = C_d W_i \quad 10.1$$

where  $C_d$  is as defined in 8.1.1.

### 10.2 Horizontal Seismic Forces

10.2.1 The horizontal seismic force at each level  $i$  shall be taken as :

$$F_i = V W_i h_i / \Sigma W_i h_i \quad 10.2$$

Provided that :

- (a) Where the height to width ratio of the horizontal load resisting system is equal to or greater than 3, then 0.1  $V$  shall be considered as concentrated at the top storey and the remaining 0.9  $V$  shall be distributed in accordance with the equation above.
- (b) For chimneys and smoke-stacks resting on the ground, 0.2  $V$  shall be considered as concentrated at the top and the remaining 0.8  $V$  shall be distributed in accordance with the equation above.
- (c) For elevated tanks, the force  $F_i$  is equal to  $V$  and acts through the centre of gravity of the total weight of the structure and contents.

10.2.2 The set of equivalent static forces specified in this clause shall be assumed to act simultaneously at each level in the direction being considered and shall be applied through points eccentric to the centre of rigidity as specified in 8.2.2.

## 11 Modal Response Spectrum Method

### 11.1 Design Spectrum

The design spectrum used for the Modal Response Spectrum Method shall as given in 8.1.2.

The relative response of each contributing mode  $i$  shall be determined by multiplying the mode response by the value of  $C(T_i)$  from 8.1.2.

## 11.2 Number of Modes to be Considered

A sufficient number of modes shall be considered to ensure that at least 90 % of the mass is participating in the direction under consideration.

## 11.3 Combination of Modal Effects

11.3.1 An established method shall be used for the combination of modal effects.

11.3.2 The combination method shall take into account the effect of closely spaced modes. Modes shall be considered to be closely spaced if their frequencies are within 15 %.

11.3.3 The combined modal effects shall be scaled by the modal combination factor,  $S$ , where :

$$S = \frac{0.9 C_d W_t}{\Sigma \text{ combined modal base shears in the direction under consideration}} \quad 11.1$$

provided that  $S$  shall not be taken as less than 1.0.

## 11.4 Torsion

### 11.4.1 General

An analysis for torsional effects may be conducted by the static method in 11.4.2.

For structures where  $e_c$  is greater than  $0.3 b$ , torsional effects should be evaluated using three-dimensional analysis and the provisions of 11.4.3.

### 11.4.2 Static Analysis for Torsional Effects

For a static analysis for torsional effects, the applied torsion at each level shall use either the forces calculated by the Seismic Coefficient Method or the combined storey inertial forces found in a translational two-dimensional modal response spectrum analysis, and a design eccentricity,  $e_d$  calculated in accordance with 8.2.2.

Torsional effects shall be combined with the translational effects by direct summation, with signs chosen to produce the most adverse combined effects in the element under consideration.

### 11.4.3 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 that producing the largest design actions in the element under consideration.

## 12 Seismic Design Requirements for Secondary Structural Elements, Architectural Finishes and Mechanical and Electrical Equipment

### 12.1 General

All architectural elements and mechanical and electrical systems shall meet the requirements of 12 as these may be a safety hazard in the event of an earthquake or may be required to be functional immediately following such an event.

Contents of museums and similar items of historical or artistic value that are non-functional items should be restrained against seismic loads. Specialist advice should be obtained for detailing such restraints.

### 12.2 Connections

All elements, components or equipment shall be positively connected to the structure to resist the specified seismic loads. Friction due to gravity shall not be used to provide the required resistance to horizontal loads.

Connections to ornamentalations, veneers, appendages and exterior panels including anchor bolts, shall be corrosion-resisting and ductile, with adequate anchorages. In the case of precast concrete panels, anchorages shall be attached to, or hooked around, panel reinforcing.

### 12.3 Separation from Structural System

Interaction with the structural system shall be avoided where specified in 12.6.1 by providing adequate separations as defined in 12.6.2.

### 12.4 Services Cut-Offs

If continued operation of a facility during strong seismic motions presents an excessive risk, an automatic shut-off system, which will operate at a pre-determined ground acceleration, not exceeding 0.2 g, shall be provided. In such cases, all equipment required for safe shut-down shall be capable of resisting the shut-off level irrespective of other requirements of this Section.

### 12.5 Design Forces

All elements and components shall be designed for a seismic force  $F_p$ , in any direction given by :

$$F_p = C_p P K_p W_p \quad 12.1$$

For elements supported by the structure,  $C_p$  is equal to  $C_a$  for the structure determined in accordance with 8.1.1 or 8.3 as appropriate.

For elements supported on the ground and independent of the structure,  $C_p$  is equal to  $C_u$  determined in accordance 8.1.1 using the element fundamental period.

#### 12.5.1 Structure Response Factor

The structural response factor,  $P$ , reflects the distribution and amplification of the ground motion by the structure supporting the particular component and shall be taken as :

$$P = 1.0 + h_i / H \quad 12.2$$

$P$  shall be taken as 1.0 for structures supported directly on the ground.

The  $P$  factor for more important elements of the structure should be calculated from a more detailed analysis using the Modal Response Spectrum Method.

#### 12.5.2 Component Seismic Performance Factor

The component seismic performance factor,  $K_p$ , is an allowance for both the estimated performance of the element or component and the importance of its performance during and immediately following an earthquake. The value of  $K_p$  shall be obtained from Table 12.1.

If the period of vibration of an element is close to that of the structure, considerable amplification may occur. If the ratio of the period of the structure to that of the element is between 0.6 and 1.4, the value of  $K_p$  shall be multiplied by .2 unless a special analysis is carried out.

ELEMENT OR COMPONENT	$K_r$
<b>GROUP A</b>	
Secondary Elements or Components :	
1. Walls and Partitions	
(a) Adjacent to an exit way, street or public place or required to have a fire resistance rating.	4
(b) Cantilevered walls and parapets.	4
(c) All walls not specified in 1(a), 1(b) or 2.	2.5
2. Stairs and their enclosing shaft walls, and shaft walls for lifts.	4
3. Veneers, exterior prefabricated panels and ornamental appendages, and their connections.	8
4. Ceilings with tiles exceeding 2 kg in weight (Refer Note 5).	3
(a) In an exit way or a ceiling required to have a fire rating.	
(b) Other ceilings not included in 4(a).	2
5. Furniture	
In an exit way or furniture that would pose a safety hazard when subject to earthquake loads.	2
6. Towers, chimneys or smoke stacks not exceeding 10 % of the mass of the building (Refer Note 3).	2.5
7. Penthouse or plant room structures on the top of a structure.	2.5
8. Horizontally cantilevered floors, beams, sunshades, etc. Note : The force acts vertically upward or downward.	5

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Table 12.1 : Component Seismic Performance Coefficient

ELEMENT OR COMPONENT	$K_p$
<b>GROUP B</b>	
Mechanical and Electrical Components :	
9. Boilers, furnaces, incinerators, water heaters or other equipment using combustible or high temperature energy sources. Pressure vessels. (Refer Note 1).	6
10. Containers and their supporting structures for (Refer Note 1) :	
(a) Toxic liquids and gases, spirits, acids, alkalis, molten metals or other such dangerous materials.	6
(b) Fire sprinkler systems including wet and dry risers	6
(c) Other	4
11. Switchgear, transformers, substations, electrical motor control devices.	6
12. Lighting fixtures :	
(a) Rigidly mounted	2.5
(b) Hanging or swinging type fixtures. (Refer Note 2)	3.5
13. Duct and piping distribution systems (Refer Note 1) :	
(a) Rigidly mounted - (i) for toxic or dangerous substances	6
(ii) other	3
(b) Flexible supports - (i) for toxic or dangerous substances	8
(ii) other	5
14. Shelving for batteries and dangerous goods (Refer Note 4).	4
15. Lift machinery, guides, etc.	3
16. Emergency standby equipment required to function immediately after an earthquake.	6

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Table 12.1 continued

Table 12.1 continued

NOTES :

1. *The seismic weight of containers and the like shall include the weight of the contents.*
2. *Hanging or swinging lights shall have a safety cable attached to the structure and the fixture, capable of supporting a lateral load equal to four times the weight.*
3. *Where towers, chimneys or smoke stacks exceed 10 % of the weight of the structure, the structure shall be analyzed considering these elements.*
4. *Shelving in Item 14 shall provide positive restraint to horizontal movement of the contents.*
5. *Suspended Ceilings :*

*Suspended ceilings with tiles weighing more than 2 kg shall satisfy the following requirements :*

- (a) *The support systems for suspended ceilings shall be designed and constructed so as to avoid sudden or incremental failure or excessive deformations that would release ceiling components.*
- (b) *Ceiling elements and lighting fixtures or other heavy fittings built into the ceiling, shall be positively anchored to their supports against a net upward force equal to one-third their weight.*
- (c) *The ceiling shall be designed for the horizontal loads in Item 4 with the support members positively connected to each other and to the building or other horizontal restraint.*

*Ceilings in important areas (such as hospital operating rooms) where loss of ceiling units cannot be tolerated, should be fixed rigidly and directly to the structure.*

*Ceilings with tiles weighing less than 2 kg need not be designed to these requirements.*

## 12.6 Separation of Elements

### 12.6.1 Applicable Elements

The requirements of 12.6.2 for the separation of elements shall apply to the following :

- (a) Elements such as stairways, rigid partitions, and non-structural masonry walls of part or full height.



- (b) Flexible partitions not capable of altering the intended structural behaviour but required to have a fire resistance rating, provided that this need not apply when it can be shown that the partition retains its fire resistance after being subjected to the specified deformation.
- (c) Precast concrete cladding and other cladding of similar mass.
- (d) Glass windows and other rigid, brittle, exterior cladding.

Elements which can accept inter-storey deflections of four times those calculated in accordance with 9 without being damaged and without affecting the structure need not comply with the separation requirements of 12.6.2.

#### **12.6.2 Separation Requirements**

Requirements for the separation from the structure of elements listed in 12.6.1 shall be as follows :

- (a) Ratio of inter-storey deflection to storey height not exceeding 0.0012 : No requirements for separation.
- (b) Ratios of inter-storey deflection to storey height exceeding 0.0012 but not greater than 0.015 or 60 mm : Elements shall be positively separated from the structure so as to allow the structure to deform as calculated in accordance with 9 without the elements coming into contact with the structure or with adjacent elements. A minimum separation of 10 mm shall be maintained between the structure and the vertical surfaces of the element. Construction tolerances shall not reduce the required separations.

### **13 Structural Variations to be Approved by Designer**

The structural designer shall make the builder or contractor aware of the dangers that can arise when structural elements or details are changed or varied without the specific approval of the structural engineer. Any variations approved by the designer shall comply with the requirements of this Standard.