

Specification for Buildings to be Built in Seismic Zones

2007

Ministry of Public Works and Settlement, Government of Republic of Turkey

Editorial note: According to the information provided by the national delegate, Seismic Code has been changed in March 2007.

Comments on Building Codes

1. General

a. Name of Country: Turkey

b. Name of Codes:

Specification for Buildings to be Built in Seismic Zones

--- in English

--- in Original Language

c. Issued by: Ministry of Public Works and Settlement, Republic of Turkey.

d. Enforcement Year: 2007

2. Structural Design Method

a. Format: (please check)

☒ Working Stress Design : Allowable Stress \geq Actual Stress

☒ Ultimate Strength Design: Ultimate Member Strength \geq Required Member Strength

☐ Limit State Design : Ultimate Lateral Strength \geq Required Lateral Strength

☒ Other Design Method : Performance-based design method:

Deformation Capacity \geq Deformation Demand

(comment)

Ultimate strength design is essential for reinforced concrete buildings. Both working stress design and ultimate strength design are applicable to steel buildings. A performance-based design method is applied for the seismic assessment and retrofit of existing reinforced concrete buildings.

b. Material Strength (Concrete and Steel):

Concrete: 20 MPa – 50 MPa

Reinforcing steel: 420 MPa

Structural steel: 235 MPa – 355 MPa. In the working stress design method, under static loads allowable tensile stress for structural steel section is 60% of the yield strength. One-third increase is allowed under seismic loads excluding the design of joints and splices.

c. Strength Reduction Factors:

Strength reductions are expressed in terms of the following material safety factors:

Concrete: 1.5

Reinforcing and structural steel: 1.15

d. Load Factors for Gravity Loadings and Load Combination:

Gravity loading: 1.4 G + 1.6 Q

Seismic loading: 1.0 G + 1.0 Q \pm 1.0 E

0.9 G \pm 1.0 E

(G: Dead load, Q: Live load, E: Earthquake load)

e. Typical Live Load Values:

Office Buildings : 3.50 kN/m²

Residential Buildings: 2.00 kN/m²

f. Special Aspects of Structural Design Method

New buildings are designed based on internal forces obtained from linear seismic analysis under reduced equivalent seismic loads for life safety. For structural systems of high ductility level, capacity design principles are fully implemented in both reinforced concrete and steel buildings.

A performance-based design method is implemented only for the seismic assessment and retrofit of existing reinforced concrete buildings. Nonlinear analysis is performed in the form of pushover analysis or response history analysis. Assessment/design verification is based on concrete and reinforcing steel strain demands/capacities in ductile deformation (plastic) zones, and strength demands/capacities in brittle behavior modes.

**Ministry of Public Works and Settlement
Government of Republic of Turkey**

**Specification for Buildings
to be Built in Seismic Zones
(2007)**

REQUIREMENTS FOR BUILDINGS TO BE BUILT IN SEISMIC ZONES

CHAPTER 1 – GENERAL REQUIREMENTS

1.1. SCOPE

1.1.1 – Requirements of this Specification shall be applicable to newly constructed buildings in seismic zones as well as to existing buildings previously constructed.

1.1.2 – Requirements applicable to existing buildings, which are subject to modification in occupancy and/or structural system and those to be assessed and retrofit before or after an earthquake are given in **Chapter 7**.

1.1.3 – Requirements of this Specification shall be applicable to reinforced concrete (cast-in-situ and prestressed or non-prestressed prefabricated) buildings, structural steel and masonry buildings and building-like structures.

1.1.4 – Until relevant code requirements are enforced, the minimum requirements and rules to be applied to timber buildings and building-like structures shall be determined by the Ministry of Public Works and Settlement and the designs shall be made accordingly.

1.1.5 – In addition to buildings and building-like structures, non-building structures permitted to be designed in accordance with the requirements of this Specification are limited with those specified in **2.12 of Chapter 2**. In this context bridges, dams, harbour structures, tunnels, pipelines, power transmission lines, nuclear power plants, natural gas storage facilities, underground structures and other structures designed with analysis and safety rules that are different than those for buildings are outside the scope of this Specification.

1.1.6 – Requirements of this Specification shall not be applied to buildings equipped with special system and equipment between foundation and soil for the purpose of isolating the building structural system from the earthquake motion, and to buildings incorporating other active and passive control systems.

1.1.7 – Requirements to be applied to structures which are outside the scope shall be specifically determined by the Ministries supervising the constructions based on contemporary international standards and such structures shall be designed to those requirements until their own special specifications are prepared.

1.2. GENERAL PRINCIPLES

1.2.1 – The general principle of earthquake resistant design to this Specification is to prevent structural and non-structural elements of buildings from any damage in low-intensity earthquakes; to limit the damage in structural and non-structural elements to repairable levels in medium-intensity earthquakes, and to prevent the overall or partial collapse of buildings in high-intensity earthquakes in order to avoid the loss of life. The performance criteria to be considered in assessment and retrofit of existing buildings are defined in **Chapter 7**.

1.2.2 – The design earthquake considered in this Specification corresponds to *high-intensity* earthquake defined in **1.2.1** above. For buildings with Building Importance Factor of $I = 1$ in accordance with **Chapter 2, Table 2.3**, the probability of exceedance of the design earthquake within a period of 50 years is 10 %. Earthquakes with different probabilities of exceedance are defined in **Chapter 7** to be considered in assessment and retrofit of existing buildings.

1.2.3 – Seismic zones cited in this Specification are the first, second, third and fourth seismic zones depicted in *Seismic Zoning Map of Turkey* prepared by the Ministry of Public Works and Settlement and issued by the decree of the Council of Ministers.

1.2.4 – Buildings to be constructed to this Code shall follow the material and workmanship requirements of “General Technical Specification” of Ministry of Public Works and Settlement.

CHAPTER 2 – ANALYSIS REQUIREMENTS FOR EARTHQUAKE RESISTANT BUILDINGS

2.0. NOTATION

$A(T)$	= Spectral Acceleration Coefficient
A_o	= Effective Ground Acceleration Coefficient
B_a	= Design internal force component of a structural element in the direction of its principal axis a
B_{ax}	= Internal force component of a structural element in the direction of its principal axis a due to earthquake in x direction
B_{ay}	= Internal force component of a structural element in the direction of its principal axis a due to earthquake in y direction perpendicular to x direction
B_b	= Design internal force quantity of a structural element in principal direction b
B_{bx}	= Internal force component of a structural element in the direction of principal axis b a due to earthquake in x direction
B_{by}	= Internal force component of a structural element in the direction of principal axis a due to earthquake in y direction perpendicular to x direction
B_B	= Any response quantity obtained by modal combination in the Mode-Superposition Method
B_D	= Amplified value of B_B
D_i	= Amplification factor to be applied in Equivalent Seismic Load Method to $\pm 5\%$ additional eccentricity at i'th storey of a torsionally irregular building
d_{fi}	= Displacement calculated at i'th storey of building under fictitious loads F_{fi}
d_i	= Displacement calculated at i'th storey of building under design seismic loads
F_{fi}	= Fictitious load acting at i'th storey in the determination of fundamental natural vibration period
F_i	= Design seismic load acting at i'th storey in Equivalent Seismic Load Method
f_e	= Equivalent seismic load acting at the mass centre of the mechanical and electrical equipment
g	= Acceleration of gravity (9.81 m/s^2)
g_i	= Total dead load at i'th storey of building
H_i	= Height of i'th storey of building measured from the top foundation level (In buildings with rigid peripheral basement walls, height of i'th storey of building measured from the top of ground floor level) [m]
H_N	= Total height of building measured from the top foundation level (In buildings with rigid peripheral basement walls, total height of building measured from the top of the ground floor level) [m]
H_w	= Total height of structural wall measured from the top foundation level or top of the ground floor level
h_i	= Height of i'th storey of building [m]
I	= Building Importance Factor
ℓ_w	= Plan length of structural wall or a piece of coupled wall
M_n	= Modal mass of the n'th natural vibration mode
M_{xn}	= Effective participating mass of the n'th natural vibration mode of building in the x earthquake direction considered
M_{yn}	= Effective participating mass of the n'th natural vibration mode of building in the y earthquake direction considered
m_i	= i'th storey mass of building ($m_i = w_i / g$)
$m_{\theta i}$	= With floors are modelled as rigid diaphragms, mass moment of inertia around vertical axis passing through mass centre of i'th storey of a building
N	= Total number of stories of building from the foundation level (In buildings with rigid peripheral basement walls, total number of stories from the ground floor level)

n	= Live Load Participation Factor
q_i	= Total live load at i'th storey of building
R	= Structural Behaviour Factor
R_{alt}, R_{ust}	= R factors specified for stories below and the roof, respectively, in the case where single-story frames with hinged columns at the top are used as roofs of cast-in-situ reinforced concrete, precast or structural steel buildings
R_{NC}	= Structural Behaviour Factor defined in Table 2.5 for the case where entire seismic loads are carried by frames of nominal ductility level
R_{YP}	= Structural Behaviour Factor defined in Table 2.5 for the case where entire seismic loads are carried by walls of high ductility level
$R_a(T)$	= Seismic Load Reduction Factor
$S(T)$	= Spectrum Coefficient
$S_{ae}(T)$	= Elastic spectral acceleration [m/s^2]
$S_{aR}(T_n)$	= Reduced spectral acceleration for the n'th natural vibration mode [m/s^2]
T	= Building natural vibration period [s]
T_1	= First natural vibration period of building [s]
T_A, T_B	= Spectrum Characteristic Periods [s]
T_m, T_n	= m'th and n'th natural vibration periods of building [s]
V_i	= Storey shear at i'th storey of building in the earthquake direction considered
V_t	= In the Equivalent Seismic Load Method, total equivalent seismic load acting on the building (base shear) in the earthquake direction considered
V_{tB}	= In the Mode-Superposition Method, total design seismic load acting on the building (base shear) obtained by modal combination in the earthquake direction considered
W	= Total weight of building calculated by considering Live Load Participation Factor
w_e	= Weight of mechanical or electrical equipment
w_i	= Weight of i'th storey of building by considering Live Load Participation Factor
Y	= Sufficient number of natural vibration modes taken into account in the Mode-Superposition Method
α	= Coefficient used for determining the gap size of a seismic joint
α_S	= Ratio of the sum of shears at the bases of structural walls of high ductility level to the base shear of the entire building
β	= Coefficient used to determine lower limits of response quantities calculated by Mode-Superposition Method
Δ_i	= Reduced storey drift of i'th storey of building
$(\Delta_i)_{ort}$	= Average reduced storey drift of i'th storey of building
ΔF_N	= Additional equivalent seismic load acting on the N'th storey (top) of building
δ_i	= Effective storey drift of i'th storey of building
$(\delta_i)_{max}$	= Maximum effective storey drift of i'th storey of building
η_{bi}	= Torsional Irregularity Factor defined at i'th storey of building
η_{ci}	= Strength Irregularity Factor defined at i'th storey of building
η_{ki}	= Stiffness Irregularity Factor defined at i'th storey of building
Φ_{xin}	= In buildings with floors modelled as rigid diaphragms, horizontal component of n'th mode shape in the x direction at i'th storey of building
Φ_{yin}	= In buildings with floors modelled as rigid diaphragms, horizontal component of n'th mode shape in the y direction at i'th storey of building
$\Phi_{\theta in}$	= In buildings with floors modelled as rigid diaphragms, rotational component of n'th mode shape around the vertical axis at i'th storey of building
θ_i	= Second Order Effect Indicator defined at i'th storey of building

2.1. SCOPE

2.1.1 – Seismic loads and analysis requirements to be applied to earthquake resistant design of all cast-in-situ and prefabricated reinforced concrete buildings, structural steel buildings and building-like structures to be built in seismic zones defined in **1.2.3** are specified in this chapter. Rules for masonry buildings are specified in **Chapter 5**.

2.1.2 – Rules for the analysis of building foundations and soil retaining structures are specified in **Chapter 6**.

2.1.3 – Non-building structures which are permitted to be analysed in accordance with the requirements of this chapter shall be limited to those given in **Section 2.12**.

2.1.4 – Analysis rules to be applied to seismic performance assessment and retrofit of existing buildings are given in **Chapter 7**.

2.2. GENERAL GUIDELINES AND RULES

2.2.1. General Guidelines for Building Structural Systems

2.2.1.1 – The building structural system resisting seismic loads as a whole as well as each structural element of the system shall be provided with sufficient stiffness, stability and strength to ensure an uninterrupted and safe transfer of seismic loads down to the foundation soil.

2.2.1.2 – The floor systems should possess sufficient stiffness and strength to ensure the safe transfer of lateral seismic loads between the elements of the structural system. Otherwise appropriate collector elements should be provided.

2.2.1.3 – In order to dissipate a significant part of the seismic energy fed into the structural system, *ductile design* principles specified in **Chapter 3** and in **Chapter 4** of this Specification should be followed.

2.2.1.4 – Design and construction of irregular buildings defined in **2.3.1** should be avoided. Structural system should be arranged symmetrical or nearly symmetrical in plan and torsional irregularity defined as type **A1** irregularity in **Table 2.1** should preferably be avoided. In this respect, it is essential that stiff structural elements such as structural walls should be placed so as to increase the torsional stiffness of the building. On the other hand, vertical irregularities defined as types **B1** and **B2** in **Table 2.1** leading to *weak storey* or *soft storey* at any storey should be avoided.

2.2.1.5 – Effects of rotations of column and in particular wall supporting foundations on soils classified as group (C) and (D) in **Table 6.1** of **Chapter 6** should be taken into account by appropriate methods of structural modelling.

2.2.2. General Rules for Seismic Loads

2.2.2.1 – Unless specified otherwise in this chapter, seismic loads acting on buildings shall be based on *Spectral Acceleration Coefficient* specified in **2.4** and *Seismic Load Reduction Factor* specified in **2.5**.

2.2.2.2 – Unless specified otherwise in this Specification, seismic loads shall be assumed to act non-simultaneously along the two perpendicular axes of the building in the horizontal plane. Rules are given in **2.7.5** for combined effects earthquakes considered.

2.2.2.3 – Unless specified otherwise in this Specification, load factors to be used to determine design internal forces under the combined effects of seismic loads and other loads according to *ultimate strength theory* shall be taken from the relevant structural specifications.

2.2.2.4 – It shall be assumed that the wind loads and seismic loads act non-simultaneously, and the most unfavourable response quantity due to wind or earthquake shall be considered for the design of each structural element. However, even if the quantities due to wind govern, rules given in this Specification shall be applied for dimensioning and detailing of structural elements and their joints.

2.3. IRREGULAR BUILDINGS

2.3.1. Definition of Irregular Buildings

Regarding the definition of irregular buildings whose design and construction should be avoided because of their unfavourable seismic behaviour, types of irregularities in plan and in elevation are given in **Table 2.1** and relevant conditions are given in **2.3.2** below.

2.3.2. Conditions for Irregular Buildings

Conditions related to irregularities defined in **Table 2.1** are given below:

2.3.2.1 – Irregularity types **A1** and **B2** govern the selection of the method of seismic analysis as specified in **2.6** below.

2.3.2.2 – In buildings with irregularity types **A2** and **A3**, it shall be verified by calculation in the first and second seismic zones that the floor systems are capable of safe transfer of seismic loads between vertical structural elements.

2.3.2.3 – In buildings with irregularity type **B1**, if total infill wall area at i 'th storey is greater than that of the storey immediately above, then infill walls shall not be taken into account in the determination of η_{ci} . In the range $0.60 \leq (\eta_{ci})_{\min} < 0.80$, Structural Behaviour Factor, given in **Table 2.5** shall be multiplied by $1.25 (\eta_{ci})_{\min}$ which shall be applicable to the entire building in both earthquake directions. In no case, however, $\eta_{ci} < 0.60$ shall be permitted. Otherwise strength and stiffness of the weak storey shall be increased and the seismic analysis shall be repeated.

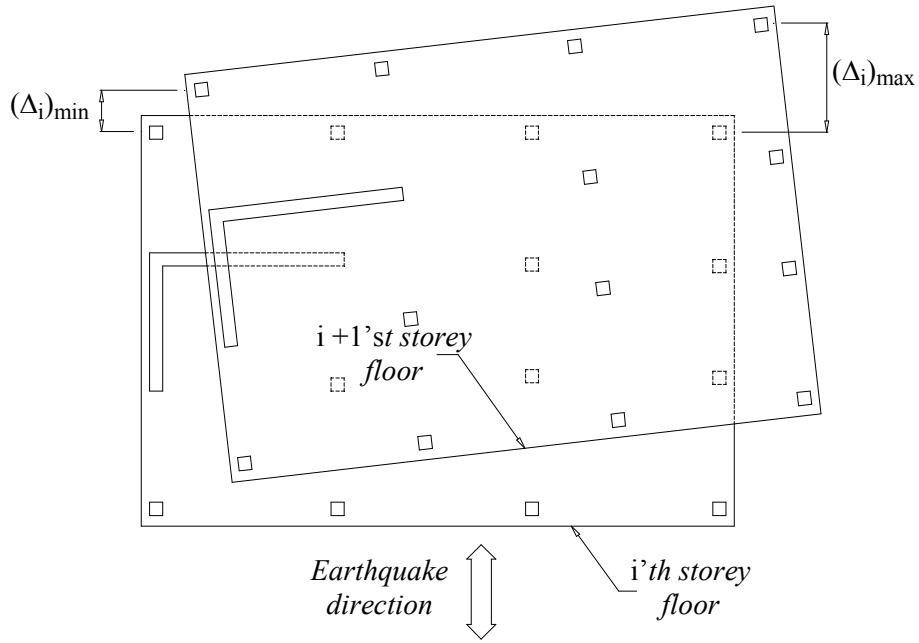
2.3.2.4 – Conditions related to buildings with irregularities of type **B3** are given below:

(a) In all seismic zones, columns at any storey of the building shall in no case be permitted to rest on the cantilever beams or on top of or at the tip of gussets provided in the columns underneath.

TABLE 2.1 – IRREGULAR BUILDINGS

A – IRREGULARITIES IN PLAN	Related Items
<p><u>A1 – Torsional Irregularity :</u> The case where <i>Torsional Irregularity Factor</i> η_{bi}, which is defined for any of the two orthogonal earthquake directions as the ratio of the maximum storey drift at any storey to the average storey drift at the same storey in the same direction, is greater than 1.2 (Fig. 2.1). $[\eta_{bi} = (\Delta_i)_{\max} / (\Delta_i)_{\text{ort}} > 1.2]$ <i>Storey drifts shall be calculated in accordance with 2.7, by considering the effects of $\pm 5\%$ additional eccentricities.</i></p>	2.3.2.1
<p><u>A2 – Floor Discontinuities :</u> In any floor (Fig. 2.2); I - The case where the total area of the openings including those of stairs and elevator shafts exceeds 1/3 of the gross floor area, II – The cases where local floor openings make it difficult the safe transfer of seismic loads to vertical structural elements, III – The cases of abrupt reductions in the in-plane stiffness and strength of floors.</p>	2.3.2.2
<p><u>A3 – Projections in Plan :</u> The cases where projections beyond the re-entrant corners in both of the two principal directions in plan exceed the total plan dimensions of the building in the respective directions by more than 20%. (Fig. 2.3).</p>	2.3.2.2
B – IRREGULARITIES IN ELEVATION	Related Items
<p><u>B1 – Interstorey Strength Irregularity (Weak Storey) :</u> In reinforced concrete buildings, the case where in each of the orthogonal earthquake directions, <i>Strength Irregularity Factor</i> η_{ci}, which is defined as the ratio of the <i>effective shear area</i> of any storey to the <i>effective shear area</i> of the storey immediately above, is less than 0.80. $[\eta_{ci} = (\sum A_e)_i / (\sum A_e)_{i+1} < 0.80]$ <i>Definition of effective shear area in any storey :</i> $\sum A_e = \sum A_w + \sum A_g + 0.15 \sum A_k$ (See 3.0 for notations)^(*)</p>	2.3.2.2
<p><u>B2 – Interstorey Stiffness Irregularity (Soft Storey) :</u> The case where in each of the two orthogonal earthquake directions, <i>Stiffness Irregularity Factor</i> η_{ki}, which is defined as the ratio of the average storey drift at any storey to the average storey drift at the storey immediately above or below, is greater than 2.0. $[\eta_{ki} = (\Delta_i/h_i)_{\text{ort}} / (\Delta_{i+1}/h_{i+1})_{\text{ort}} > 2.0$ or $\eta_{ki} = (\Delta_i/h_i)_{\text{ort}} / (\Delta_{i-1}/h_{i-1})_{\text{ort}} > 2.0]$ <i>Storey drifts shall be calculated in accordance with 2.7, by considering the effects of $\pm 5\%$ additional eccentricities.</i></p>	2.3.2.1
<p><u>B3 – Discontinuity of Vertical Structural Elements :</u> The cases where vertical structural elements (columns or structural walls) are removed at some stories and supported by beams or gusseted columns underneath, or the structural walls of upper stories are supported by columns or beams underneath (Fig. 2.4).</p>	2.3.2.4

^(*) See APPENDIX



In the case where floors behave as rigid diaphragms in their own planes:

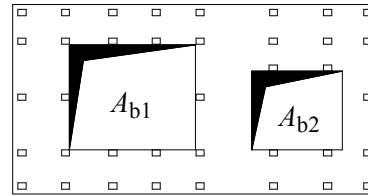
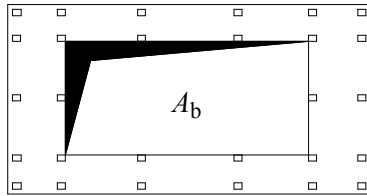
$$(\Delta_i)_{ort} = 1/2 [(\Delta_i)_{max} + (\Delta_i)_{min}]$$

Torsional irregularity factor:

$$\eta_{bi} = (\Delta_i)_{max} / (\Delta_i)_{ort}$$

Torsional irregularity: $\eta_{bi} > 1.2$

Figure 2.1



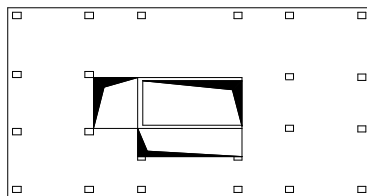
$$A_b = A_{b1} + A_{b2}$$

Type A2 irregularity - I

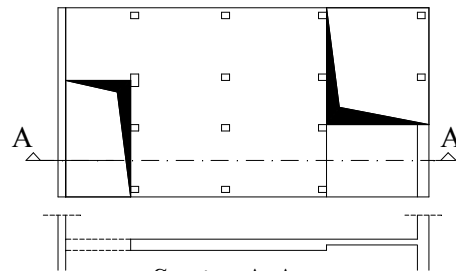
$$A_b / A > 1/3$$

A_b : Total area of openings

A : Gross floor area

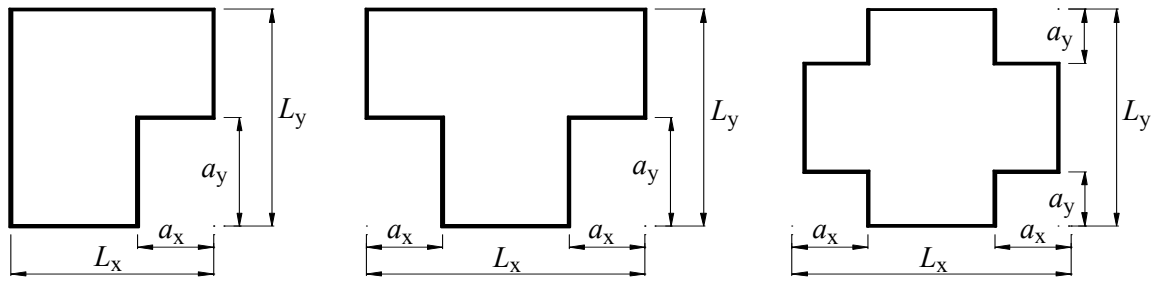


Type A2 irregularity - II



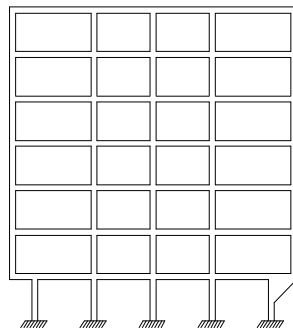
Section A-A
Type A2 irregularity - II and III

Figure 2.2

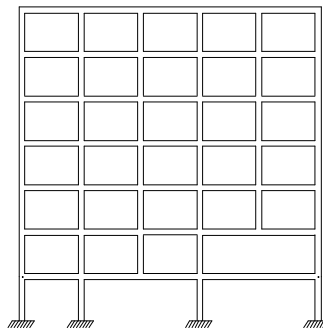


Type A3 irregularity :
 $a_x > 0.2 L_x$ and at the same time $a_y > 0.2 L_y$

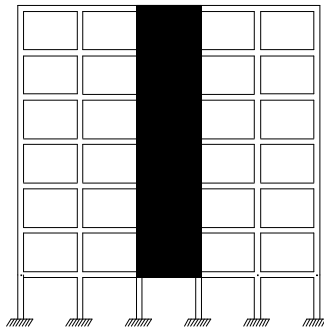
Figure 2.3



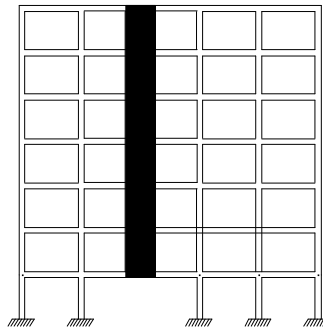
See 2.3.2.4 (a)



See 2.3.2.4 (b)



See 2.3.2.4 (c)



See 2.3.2.4 (d)

Figure 2.4

(b) In the case where a column rests on a beam which is supported at both ends, all internal force components induced by the combined vertical loads and seismic loads in the earthquake direction considered shall be increased by 50% at all sections of the beam and at all sections of the other beams and columns adjoining to the beam.

(c) In no case the walls shall be permitted to rest on columns underneath.

(d) Structural walls shall in no case be permitted in their own plane to rest on the beam span at any storey of the building.

2.4. DEFINITION OF ELASTIC SEISMIC LOADS: SPECTRAL ACCELERATION COEFFICIENT

The *Spectral Acceleration Coefficient*, $A(T)$, to be considered for determining seismic loads is given by **Eq.(2.1)**. The *elastic spectral acceleration*, $S_{ae}(T)$, which is defined as the ordinate of 5% damped elastic *Design Acceleration Spectrum*, is equal to spectral acceleration coefficient times the acceleration of gravity, g .

$$\begin{aligned} A(T) &= A_0 I S(T) \\ S_{ae}(T) &= A(T) g \end{aligned} \quad (2.1)$$

2.4.1. Effective Ground Acceleration Coefficient

The *Effective Ground Acceleration Coefficient*, A_0 , introduced in **Eq.(2.1)** is specified in **Table 2.2**.

TABLE 2.2 – EFFECTIVE GROUND ACCELERATION COEFFICIENT (A_0)

<i>Seismic Zone</i>	A_0
1	0.40
2	0.30
3	0.20
4	0.10

2.4.2. Building Importance Factor

The *Building Importance Factor*, I , given in **Eq.(2.1)** is specified in **Table 2.3**.

TABLE 2.3 – BUILDING IMPORTANCE FACTOR (I)

<i>Purpose of Occupancy or Type of Building</i>	<i>Importance Factor (I)</i>
<u>1. Buildings to be utilised after the earthquake and buildings containing hazardous materials</u> a) Buildings required to be utilised immediately after the earthquake (Hospitals, dispensaries, health wards, fire fighting buildings and facilities, PTT and other telecommunication facilities, transportation stations and terminals, power generation and distribution facilities; governorate, county and municipality administration buildings, first aid and emergency planning stations) b) Buildings containing or storing toxic, explosive and flammable materials, etc.	1.5
<u>2. Intensively and long-term occupied buildings and buildings preserving valuable goods</u> a) Schools, other educational buildings and facilities, dormitories and hostels, military barracks, prisons, etc. b) Museums	1.4
<u>3. Intensively but short-term occupied buildings</u> Sport facilities, cinema, theatre and concert halls, etc.	1.2
<u>4. Other buildings</u> Buildings other than above-defined buildings. (Residential and office buildings, hotels, building-like industrial structures, etc.)	1.0

2.4.3. Spectrum Coefficient

2.4.3.1 – The *Spectrum Coefficient*, $S(T)$, given in **Eq.(2.1)** shall be determined by **Eqs.(2.2)**, depending on local site conditions and the building natural period, T (**Fig.2.5**):

$$\begin{aligned} S(T) &= 1 + 1.5 \frac{T}{T_A} & (0 \leq T \leq T_A) \\ S(T) &= 2.5 & (T_A < T \leq T_B) \\ S(T) &= 2.5 \left(\frac{T_B}{T} \right)^{0.8} & (T_B < T) \end{aligned} \quad (2.2)$$

Spectrum Characteristic Periods, T_A and T_B , shown in **Eq.(2.2)** are specified in **Table 2.4**, depending on *Local Site Classes* defined in **Table 6.2** of **Chapter 6**^(*).

TABLE 2.4 – SPECTRUM CHARACTERISTIC PERIODS (T_A , T_B)

<i>Local Site Class acc. to Table 12.2</i>	T_A (second)	T_B (second)
Z1	0.10	0.30
Z2	0.15	0.40
Z3	0.15	0.60
Z4	0.20	0.90

2.4.3.2 - In case where the requirements specified in **6.2.1.2** and **6.2.1.3** of **Chapter 6** are not met, spectrum characteristic periods defined in **Table 2.4** for local site class Z4 shall be used.

2.4.4. Special Design Acceleration Spectra

When required, elastic acceleration spectrum may be determined through special investigations by considering local seismic and site conditions. However spectral acceleration coefficients corresponding to so obtained acceleration spectrum ordinates shall in no case be less than those determined by **Eq.(2.1)** based on relevant characteristic periods specified in **Table 2.4**.

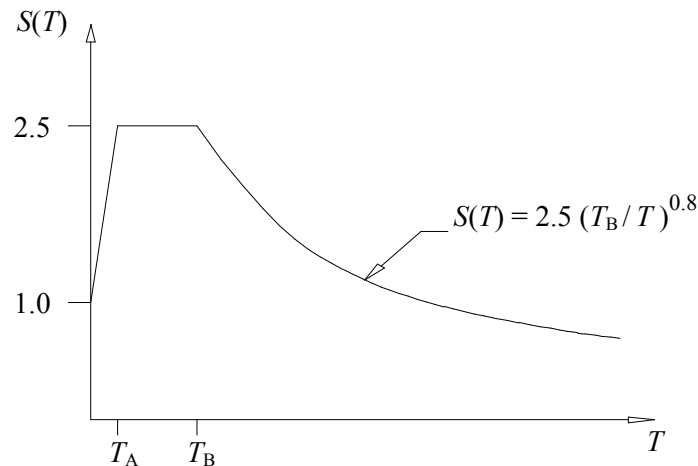


Figure 2.5

^(*) See APPENDIX

2.5. REDUCTION OF ELASTIC SEISMIC LOADS: SEISMIC LOAD REDUCTION FACTOR

Elastic seismic loads determined in terms of *spectral acceleration coefficient* defined in 2.4 shall be divided to below-defined *Seismic Load Reduction Factor* to account for the specific nonlinear behaviour of the structural system during earthquake. *Seismic Load Reduction Factor*, $R_a(T)$, shall be determined by **Eqs.(2.3)** in terms of *Structural Behaviour Factor*, R , defined in **Table 2.5** below for various structural systems, and the natural vibration period T .

$$\begin{aligned} R_a(T) &= 1.5 + (R - 1.5) \frac{T}{T_A} & (0 \leq T \leq T_A) \\ R_a(T) &= R & (T_A < T) \end{aligned} \quad (2.3)$$

2.5.1. General Conditions on Ductility Levels of Structural Systems

2.5.1.1 – Definitions of and requirements to be fulfilled for *structural systems of high ductility level* and *structural systems of nominal ductility level*, for which Structural Behaviour Factors are specified in **Table 2.5**, are given in **Chapter 3** for reinforced concrete buildings and in **Chapter 4** for structural steel buildings.

2.5.1.2 – In structural systems denoted as being *high ductility level* in **Table 2.5**, ductility levels shall be high in both lateral earthquake directions. Systems of high ductility or mixed ductility level in one earthquake direction and of nominal ductility level in the perpendicular earthquake direction shall be deemed to be *structural systems of nominal ductility level* in both directions.

2.5.1.3 – In structural systems where ductility levels are the same in both directions or those with high ductility level in one direction and mixed ductility level in the other direction, different R factors may be used in different directions.

2.5.1.4 – Reinforced concrete flat slab systems without structural walls as well as bare or infilled joist and waffle slab systems whose columns and beams do not satisfy the requirements given in 3.3, 3.4 and 3.5 shall be treated as *systems of nominal ductility level*.

2.5.1.5 – In the first and second seismic zones;

(a) Excluding paragraph (b) below, the use of *structural systems of high ductility level* is mandatory for buildings with structural systems comprised of frames only.

(b) In structural steel buildings with Building Importance Factor to **Table 2.3** is $I = 1.2$ and $I = 1.0$, structural systems composed of only frames of nominal ductility level may be used, provided that the condition of $H_N \leq 16$ m is met.

(c) In all buildings with Building Importance Factor to **Table 2.3** is $I = 1.5$ and $I = 1.4$, *structural systems of high ductility level* or *structural systems of mixed ductility* defined in 2.5.4.1 shall be used.

2.5.1.6 – *Structural systems of nominal ductility level* without structural walls may be permitted only in the third and fourth seismic zones with the following conditions:

(a) Reinforced concrete buildings defined in 2.5.1.4 may be constructed provided that $H_N \leq 13$ m.

(b) Excluding those defined in 2.5.1.4, reinforced concrete and structural steel buildings with structural systems comprised of only frames of nominal ductility level can be constructed provided that $H_N \leq 25$ m.

TABLE 2.5 – STRUCTURAL BEHAVIOUR FACTORS (R)

BUILDING STRUCTURAL SYSTEM	Systems of Nominal Ductility Level	Systems of High Ductility Level
<u>(1) CAST-IN-SITU REINFORCED CONCRETE BUILDINGS</u>		
(1.1) Buildings in which seismic loads are fully resisted by frames.....	4	8
(1.2) Buildings in which seismic loads are fully resisted by coupled structural walls.....	4	7
(1.3) Buildings in which seismic loads are fully resisted by solid structural walls.....	4	6
(1.4) Buildings in which seismic loads are jointly resisted by frames and solid and/or coupled structural walls.....	4	7
<u>(2) PREFABRICATED REINFORCED CONCRETE BUILDINGS</u>		
(2.1) Buildings in which seismic loads are fully resisted by frames with connections capable of cyclic moment transfer	3	7
(2.2) Buildings in which seismic loads are fully resisted by single-storey frames with columns hinged at top.....	—	3
(2.3) Prefabricated buildings in which seismic loads are fully resisted by prefabricated or cast-in-situ solid and/or coupled structural walls with hinged frame connections	—	5
(2.4) Buildings in which seismic loads are jointly resisted by frames with connections capable of cyclic moment transfer and cast-in-situ solid and/or coupled structural walls	3	6
<u>(3) STRUCTURAL STEEL BUILDINGS</u>		
(3.1) Buildings in which seismic loads are fully resisted by frames.....	5	8
(3.2) Buildings in which seismic loads are fully resisted by single-storey frames with columns hinged at top.....	—	4
(3.3) Buildings in which seismic loads are fully resisted by braced frames or cast-in-situ reinforced concrete structural walls		
(a) <i>Centrally braced frames</i>	4	5
(b) <i>Eccentrically braced frames</i>	—	7
(c) <i>Reinforced concrete structural walls</i>	4	6
(3.4) Buildings in which seismic loads are jointly resisted by frames and braced frames or cast-in-situ reinforced concrete structural walls		
(a) <i>Centrally braced frames</i>	5	6
(b) <i>Eccentrically braced frames</i>	—	8
(c) <i>Reinforced concrete structural walls</i>	4	7

2.5.2. Conditions for Solid Structural Wall-Frame Systems of High Ductility Level

Requirements for buildings where seismic loads are jointly resisted by reinforced concrete solid structural walls of *high ductility level* and reinforced concrete or structural steel frames of *high ductility level* are given below:

2.5.2.1 – In order that $R=7$ can be used for the cases with cast-in-situ reinforced concrete and steel frames or $R=6$ for the case with prefabricated reinforced concrete frames as given in **Table 2.5**, sum of bending shears developed at the bases of solid structural walls under seismic loads shall not exceed 75% of the total base shear developed for the entire building ($\alpha_S \leq 0.75$).

2.5.2.2 – In the case where the requirement given in **2.5.2.1** cannot be satisfied, R factor to be used in the range $0.75 < \alpha_S \leq 1.0$ shall be determined with $R = 10 - 4 \alpha_S$ for the cases with cast-in-situ reinforced concrete and steel frames and with $R = 9 - 4 \alpha_S$ for the case with prefabricated reinforced concrete frames.

2.5.2.3 – In structural walls of $H_w / \ell_w \leq 2.0$, internal forces calculated according to above-defined R factors shall be amplified by multiplying them with $[3 / (1 + H_w / \ell_w)]$. However amplification factor shall not be taken more than 2.

2.5.3. Conditions on Mandatory Use of Structural Walls in Certain Systems of Nominal Ductility Level

Structural systems of nominal ductility level defined in paragraphs (a) and (b) of **2.5.1.6** can also be constructed in all seismic zones as well as above the height limits defined in the same paragraphs. However in such cases it is mandatory to have solid or coupled structural walls of high ductility level or nominal ductility level in full height of reinforced concrete buildings, and concentric or eccentric braced frames of high ductility level or nominal ductility level in structural steel buildings.

2.5.3.1 – In the case where structural walls of *nominal ductility level* are used in the structural system, the sum of shears obtained in each earthquake direction from seismic loads at the bases structural walls shall be more than 75% of the total base shear developed for the entire building.

2.5.3.2 – In the case where structural walls of *high ductility level* are used in the structural system, requirements given below in **2.5.4.1** for mixed structural systems shall be applied.

2.5.4. Conditions for Structural Systems of Mixed Ductility

2.5.4.1 – Structural systems of nominal ductility level defined in paragraphs (a) and (b) of **2.5.1.6** may be used in combination with structural walls of *high ductility level*. Reinforced concrete solid and coupled structural walls or concentric or eccentric braced frames (for steel buildings) may be used in such structural systems with *mixed systems of ductility levels*, provided that the following conditions are satisfied.

(a) In the analysis of such mixed systems, frames and walls shall be considered jointly, however in all cases $\alpha_S \geq 0.40$ shall be satisfied in each earthquake direction.

(b) When $\alpha_S \geq 2/3$ is satisfied in both earthquake directions, R factor defined in **Table 2.5** for the case where seismic loads are fully resisted by structural walls of *high ductility level* ($R = R_{YP}$) may be used for the entire structural system.

(c) In the range $0.40 < \alpha_S < 2/3$, the relationship of $R = R_{NC} + 1.5 \alpha_S (R_{YP} - R_{NC})$ shall be applied in both earthquake directions.

2.5.4.2 – Reinforced concrete rigid peripheral walls used in basements of buildings shall not be taken into consideration as parts of structural wall systems or structural wall-frame systems given in **Table 2.5**. Rules to be applied to such buildings are given in **2.7.2.4** and **2.8.3.2**.

2.5.5. Conditions for Buildings with Columns Hinged at Top

2.5.5.1 – In reinforced concrete buildings comprised of single-storey frames with columns hinged at top;

(a) In the case of cast-in-situ reinforced concrete columns, R factor defined for prefabricated buildings in (2.2) of **Table 2.5** shall be used.

(b) Requirements applicable to prefabricated reinforced concrete and steel buildings are given in **2.5.5.2**, for which R factors are specified in (2.2) and (3.2) of **Table 2.5**. The requirements for the use of such frames as the top storey (roof) of cast-in-situ concrete, prefabricated or steel buildings are given in **2.5.5.3**.

2.5.5.2 – A single, partial mezzanine floor can be constructed inside of such single-storey buildings with no more than 25% of plan area of the building. Structural system of mezzanine floor may be taken into account in the seismic analysis together with the main structural frames. In such a case the combined system shall be designed as a system of high ductility level. It shall be checked whether torsional irregularity defined in **Table 2.1** exists in the combined system and if existed it shall be considered in the analysis. The joints of mezzanine floor with the main frames may be hinged or monolithic connection.

2.5.5.3 – In the case where single-storey frames with columns hinged at top are used as the top storey (roof) of cast-in-situ concrete, prefabricated or steel buildings, R factor defined at (2.2) or (3.2) of **Table 2.5** for top storey, ($R_{üst}$), and the R factor that could be defined differently for the lower stories, (R_{alt}), may be used jointly, provided that the following conditions are met.

(a) Initially seismic analysis shall be performed according to **2.7** or **2.8** with $R = R_{alt}$ considered for the entire building. Reduced and effective story drifts defined in **2.10.1** shall be obtained from this analysis for the entire building.

(b) Internal forces of the top storey shall be obtained by multiplying the internal forces calculated at (a) by the ratio ($R_{alt} / R_{üst}$).

(c) Internal forces of the lower stories shall be made of two parts. The first part are those calculated at (a). The second part shall be obtained additionally by applying the forces calculated at (b) as support reactions of top storey columns to the structural system of the lower stories after multiplying them by $(1 - R_{üst} / R_{alt})$.

2.6. SELECTION OF ANALYSIS METHOD

2.6.1. Analysis Methods

Methods to be used for the seismic analysis of buildings and building-like structures are, *Equivalent Seismic Load Method* given in 2.7, *Mode-Combination Method* given in 2.8 and *Analysis Methods in the Time Domain* given in 2.9. Methods given in 2.8 and 2.9 may be used for the seismic analysis of all buildings and building-like structures.

2.6.2. Application Limits of Equivalent Seismic Load Method

Buildings for which *Equivalent Seismic Load Method* given in 2.7 is applicable are summarised in **Table 2.6**. Methods given in 2.8 or 2.9 shall be used for the seismic analysis of buildings outside the scope of **Table 2.6**.

TABLE 2.6 – BUILDINGS FOR WHICH EQUIVALENT SEISMIC LOAD METHOD IS APPLICABLE

<i>Seismic Zone</i>	<i>Type of Building</i>	<i>Total Height Limit</i>
1, 2	Buildings with torsional irregularity coefficient satisfying the condition $\eta_{bi} \leq 2.0$ at every storey	$H_N \leq 25$ m
1, 2	Buildings with torsional irregularity coefficient satisfying the condition $\eta_{bi} \leq 2.0$ at every storey and at the same time without type B2 irregularity	$H_N \leq 40$ m
3, 4	All buildings	$H_N \leq 40$ m

2.7. EQUIVALENT SEISMIC LOAD METHOD

2.7.1. Determination of Total Equivalent Seismic Load

2.7.1.1 – *Total Equivalent Seismic Load* (base shear), V_t , acting on the entire building in the earthquake direction considered shall be determined by **Eq.(2.4)**.

$$V_t = \frac{WA(T_1)}{R_a(T_1)} \geq 0.10 A_0 I W \quad (2.4)$$

The first natural vibration period of the building, T_1 , shall be calculated in accordance with 2.7.4.

2.7.1.2 – Total building weight, W , to be used in **Eq.(2.4)** as the seismic weight shall be determined by **Eq.(2.5)**.

$$W = \sum_{i=1}^N w_i \quad (2.5)$$

Storey weights w_i of **Eq.(2.5)** shall be calculated by **Eq.(2.6)**.

$$w_i = g_i + n q_i \quad (2.6)$$

Live Load Participation Factor, n , shown in **Eq.(2.6)** is given in **Table 2.7**. In industrial buildings, $n = 1$ shall be taken for fixed equipment weights while crane payloads shall not be taken into account in the calculation of storey weights. In the calculation of roof weights for seismic loads, 30% of snow loads shall be considered.

TABLE 2.7 – LIVE LOAD PARTICIPATION FACTOR (n)

<i>Purpose of Occupancy of Building</i>	<i>n</i>
Depot, warehouse, etc.	0.80
School, dormitory, sport facility, cinema, theatre, concert hall, car park, restaurant, shop, etc.	0.60
Residence, office, hotel, hospital, etc.	0.30

2.7.2. Determination of Design Seismic Loads Acting at Storey Levels

2.7.2.1 – Total equivalent seismic load determined by **Eq.(2.4)** is expressed by **Eq. (2.7)** as the sum of equivalent seismic loads acting at storey levels (**Fig. 2.6a**):

$$V_t = \Delta F_N + \sum_{i=1}^N F_i \quad (2.7)$$

2.7.2.2 – The value of *additional equivalent seismic load*, ΔF_N , acting at the N 'th storey (roof) of the building shall be determined by **Eq.(2.8)**.

$$\Delta F_N = 0.0075 N V_t \quad (2.8)$$

2.7.2.3 – Excluding ΔF_N , the remaining part of the total equivalent seismic load shall be distributed to stories of the building (including N 'th storey) in accordance with **Eq.(2.9)**.

$$F_i = (V_t - \Delta F_N) \frac{w_i H_i}{\sum_{j=1}^N w_j H_j} \quad (2.9)$$

2.7.2.4 – In buildings with reinforced concrete peripheral walls at their basements being very rigid relative to upper stories and basement floors behaving as rigid diaphragms in horizontal planes, equivalent seismic loads acting on the basement stories and on the upper stories shall be calculated independently as in the following. These loads shall be applied together to the combined structural system.

(a) In determining the total equivalent seismic load and equivalent storey seismic loads in accordance with **2.7.1.1**, **2.7.2.2** and **2.7.2.3**, appropriate R factor shall be selected from **Table 2.5** without considering the rigid peripheral basement walls and seismic weights of the upper stories only shall be taken into account. In this case, foundation top level considered in the relevant definitions and expressions shall be replaced by the ground floor level. Fictitious loads used for the calculation of the first natural vibration period in accordance with **2.7.4.1** shall also be based on seismic weights of the upper stories only (**Fig.2.6b**).

(b) In calculating equivalent seismic loads acting on rigid basement stories, seismic weights of basements only shall be taken into account and calculation shall be independent of upper stories. For such parts of the building, *Spectrum Coefficient* shall be taken as $S(T) = 1$ without calculating the natural vibration period. In determining equivalent seismic loads acting on each basement storey, spectral acceleration obtained from **Eq.(2.1)** shall be multiplied directly with the respective weight of the storey and resulting elastic loads shall be reduced by dividing them to $R_a(T) = 1.5$ (**Fig.2.6c**).

(c) In-plane strength of ground floor system, which is surrounded by very stiff basement walls and located in the transition zone between upper stories, shall be checked according to the internal forces obtained from this analysis.

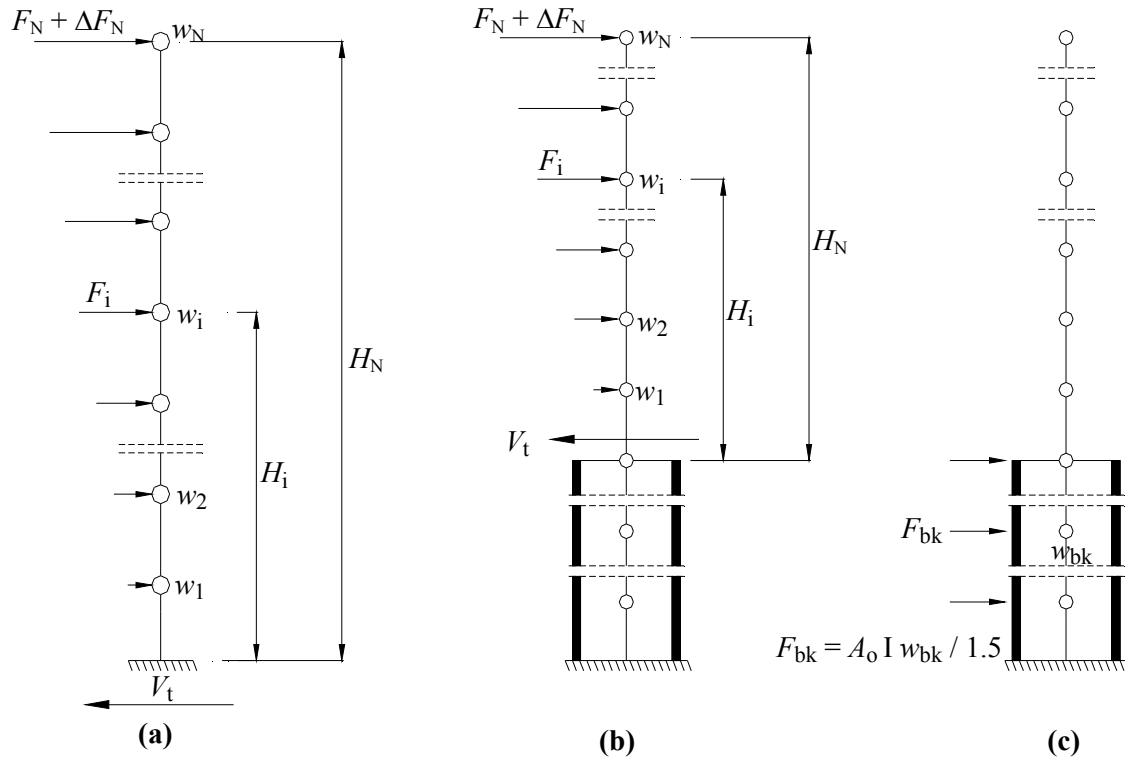


Figure 2.6

2.7.3. Displacement Components to be Considered and Application Points of Seismic Loads

2.7.3.1 – In buildings where floors behave as rigid horizontal diaphragms, two lateral displacement components and the rotation around the vertical axis shall be taken into account at each floor as independent static displacement components. At each floor, equivalent seismic loads determined in accordance with 2.7.2 shall be applied to the floor mass centre as well as to the points defined by shifting it +5% and –5% of the floor length in the perpendicular direction to the earthquake direction considered in order to account for the *additional eccentricity effects* (**Fig. 2.7**).

2.7.3.2 – In buildings where type **A2** irregularity exists and floors do not behave as rigid horizontal diaphragms, sufficient number of independent static displacement components shall be considered to account for the in-plane deformation of floors. In order to consider additional eccentricity effects, each of the seismic loads acting on the individual masses distributed over each floor shall be shifted by +5% and –5% of the floor length in perpendicular direction to the earthquake direction considered (**Fig. 2.8**).

2.7.3.3 – In the case where type **A1** irregularity defined in **Table 2.1** exists at any i 'th storey such that the condition $1.2 < \eta_{bi} \leq 2.0$ is satisfied, $\pm 5\%$ additional eccentricity applied to this floor according to 2.7.3.1 and/or 2.7.3.2 shall be amplified by multiplying with coefficient D_i given by **Eq.(2.10)** for both earthquake directions.

$$D_i = \left(\frac{\eta_{bi}}{1.2} \right)^2 \quad (2.10)$$

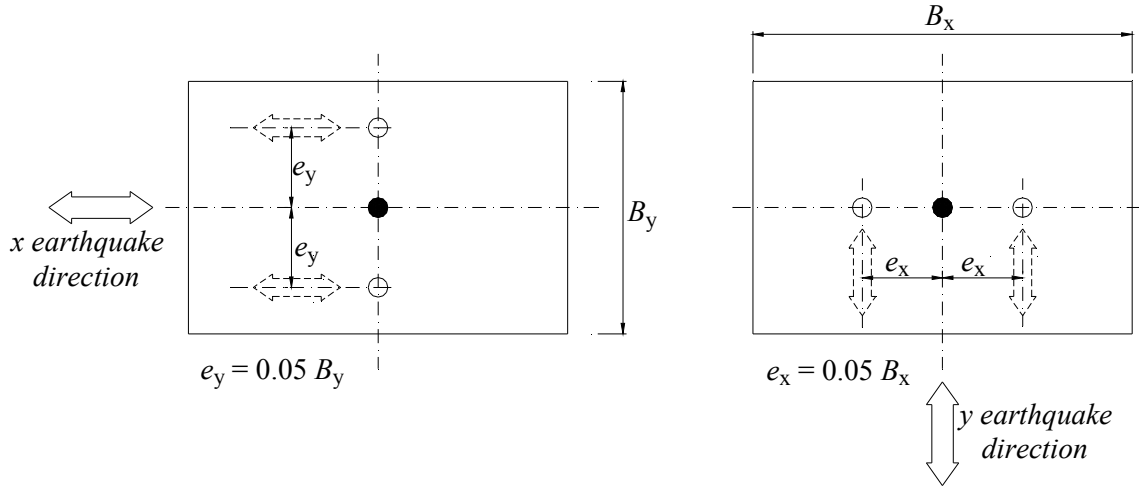


Figure 2.7

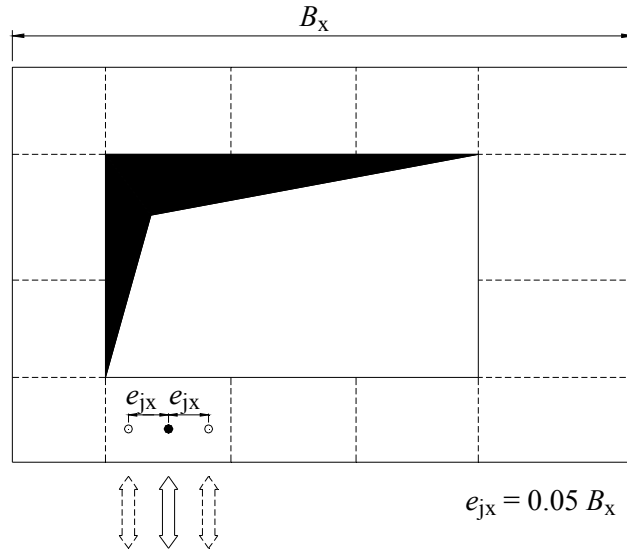


Figure 2.8

2.7.4. Determination of First Natural Vibration Period of Building

2.7.4.1 – In the case where Equivalent Seismic Load Method is applied, the natural vibration period of the building dominant in the earthquake direction shall not be taken longer than the value calculated by **Eq.(2.11)**.

$$T_1 = 2\pi \left(\frac{\sum_{i=1}^N m_i d_{fi}^2}{\sum_{i=1}^N F_{fi} d_{fi}} \right)^{1/2} \quad (2.11)$$

Fictitious load F_{fi} acting on the i 'th storey shall be obtained from **Eq.(2.9)** by substituting any value (for example a unit value) in place of $(V_t - \Delta F_N)$, see **Fig. 2.9**.

2.7.4.2 – Regardless of the value calculated by **Eq.(2.11)**, natural period shall not be taken longer than $0.1N$ in buildings with $N > 13$ excluding basement(s).

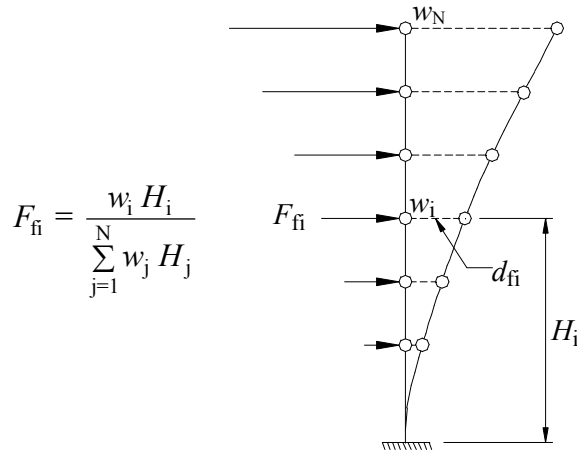


Figure 2.9

2.7.5. Internal forces in Element Principal Axes

Under the combined effects of independently acting x and y direction earthquakes to the structural system, internal forces in element principal axes a and b shall be obtained by **Eq.(2.12)** such that the most unfavourable results yield (**Fig. 2.10**).

$$\begin{aligned} B_a &= \pm B_{ax} \pm 0.30 B_{ay} & \text{veya} & B_a = \pm 0.30 B_{ax} \pm B_{ay} \\ B_b &= \pm B_{bx} \pm 0.30 B_{by} & \text{veya} & B_b = \pm 0.30 B_{bx} \pm B_{by} \end{aligned} \quad (2.12)$$

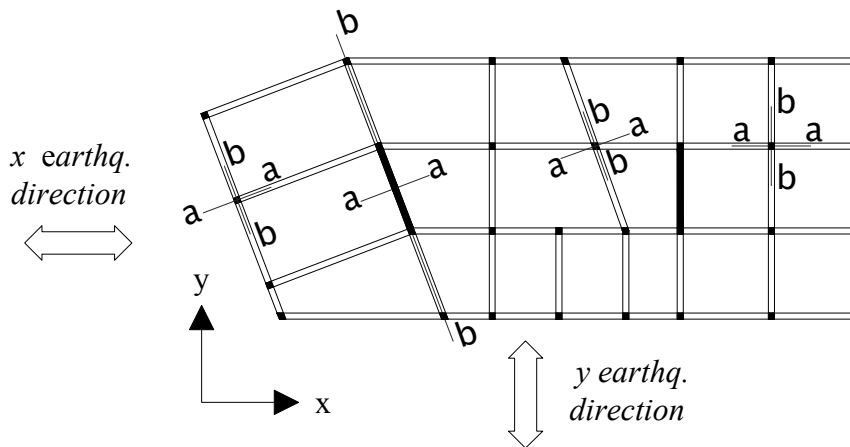


Figure 2.10

2.8. MODE COMBINATION METHOD

In this method, maximum internal forces and displacements are determined by the statistical combination of maximum contributions obtained from each of the sufficient number of natural vibration modes considered.

2.8.1. Acceleration Spectrum

Reduced acceleration spectrum ordinate to be taken into account in any n'th vibration mode shall be determined by **Eq.(2.13)**.

$$S_{aR}(T_n) = \frac{S_{ae}(T_n)}{R_a(T_n)} \quad (2.13)$$

In the case where elastic design acceleration spectrum is determined through special investigations in accordance with 2.4.4, relevant spectrum ordinate shall be considered in Eq.(2.13) in lieu of $S_{ae}(T_n)$.

2.8.2. Dynamic Degrees of Freedom to be Considered

2.8.2.1 – In buildings where floors behave as rigid horizontal diaphragms, two horizontal degrees of freedom in perpendicular directions and a rotational degree of freedom with respect to the vertical axis passing through mass centre shall be considered at each storey. At each floor, modal seismic loads shall be determined for those degrees of freedom and shall be applied to the floor mass centre as well as to the points defined by shifting it +5% and –5% of the floor length in the perpendicular direction to the earthquake direction considered in order to account for the *additional eccentricity effects* (Fig. 2.7).

2.8.2.2 – In buildings where type A2 irregularity exists and floors do not behave as rigid horizontal diaphragms, sufficient number of dynamic degrees of freedom shall be considered to account for the in-plane deformation of floors. In order to consider additional eccentricity effects, each of the modal seismic loads acting on the individual masses distributed over each floor shall be shifted by +5% and –5% of the floor length in perpendicular direction to the earthquake direction considered (Fig. 2.8). In such buildings, internal force and displacement quantities due to additional eccentricity effects alone may also be calculated in accordance with 2.7. Such quantities shall be directly added to those combined in accordance with below given 2.8.4 without taking into account additional eccentricity effects.

2.8.3. Sufficient Number of Vibration Modes to be Considered

2.8.3.1 – *Sufficient number of vibration modes*, Y, to be taken into account in the analysis shall be determined to the criterion that the sum of effective participating masses calculated for each mode in each of the given x and y perpendicular lateral earthquake directions shall in no case be less than 90% of the total building mass.

$$\begin{aligned} \sum_{n=1}^Y M_{xn} &= \sum_{n=1}^Y \frac{L_{xn}^2}{M_n} \geq 0.90 \sum_{i=1}^N m_i \\ \sum_{n=1}^Y M_{yn} &= \sum_{n=1}^Y \frac{L_{yn}^2}{M_n} \geq 0.90 \sum_{i=1}^N m_i \end{aligned} \quad (2.14)$$

The expressions of L_{xn} , L_{yn} and modal mass M_n shown in Eqs.(2.14) are given below for buildings with rigid floor diaphragms:

$$\begin{aligned} L_{xn} &= \sum_{i=1}^N m_i \Phi_{xin} \quad ; \quad L_{yn} = \sum_{i=1}^N m_i \Phi_{yin} \\ M_n &= \sum_{i=1}^N (m_i \Phi_{xin}^2 + m_i \Phi_{yin}^2 + m_{\theta i} \Phi_{\theta in}^2) \end{aligned} \quad (2.15)$$

2.8.3.2 – In buildings with reinforced concrete peripheral walls at their basements being very rigid relative to upper stories and basement floors behaving as rigid diaphragms in horizontal planes, it may be sufficed with the consideration of vibration modes which are effective in the upper stories only. In this case, in the analysis performed by the Mode Combination Method which corresponds to the analysis by Equivalent Seismic Load Method as given in Paragraph (a) of 2.7.2.4, the coefficient R shall be selected from **Table 2.5** without considering the rigid peripheral basement walls whereas the upper storey masses only shall be taken into account. Paragraphs (b) and (c) of 2.7.2.4 shall be applied as they are given for Equivalent Seismic Load Method.

2.8.4. Modal Combination

Rules to be applied for the statistical combination of non-simultaneous maximum contributions of response quantities calculated for each vibration mode, such as the base shear, storey shear, internal force components, displacements and storey drifts, are specified in the following *provided that they are applied independently for each response quantity*:

2.8.4.1 – In the cases where natural periods of any two vibration mode with $T_m < T_n$ always satisfy the condition $T_m / T_n < 0.80$, *Square Root of Sum of Squares (SRSS) Rule* may be applied for the combination of maximum modal contributions.

2.8.4.2 – In the cases where the above given condition is not satisfied, *Complete Quadratic Combination (CQC) Rule* shall be applied for the combination of maximum modal contributions. In the calculation of *cross correlation coefficients* to be used in the application of the rule, modal damping factors shall be taken as 5% for all modes.

2.8.5. Lower Limits of Response Quantities

In the case where the ratio of the base shear in the given earthquake direction, V_{tB} , which is obtained through modal combination according to 2.8.4, to the base shear, V_t , obtained by Equivalent Seismic Load Method through Eq.2.4 is less than the below given value of β ($V_{tB} < \beta V_t$), all internal force and displacement quantities determined by Mode Combination Method shall be amplified in accordance with Eq.(2.16).

$$B_D = \frac{\beta V_t}{V_{tB}} B_B \quad (2.16)$$

If at least one of the irregularities of type **A1**, **B2** or **B3** defined in **Table 2.1** exists in a building $\beta=0.90$, whereas none of them exists $\beta=0.80$ shall be used in Eq. (2.16).

2.8.6. Internal forces in Element Principal Axes

Under the combined effects of independently acting x and y direction earthquakes to the structural system, the directional combination rule given in 2.7.5 shall be additionally applied to the internal forces obtained in element principal axes a and b by modal combination according to 2.8.4 – see **Fig. 2.10**.

2.9. ANALYSIS METHODS IN TIME DOMAIN

Artificially generated, previously recorded or simulated earthquake ground motions can be used in linear or nonlinear seismic analysis of buildings and building-like structures in the time domain.

2.9.1. Artificial Earthquake Ground Motions

In the case where artificial ground motions are used, at least three earthquake ground motions shall be generated with the following properties.

(a) The duration of the strong motion part shall neither be shorter than 5 times the fundamental period of the building nor 15 seconds.

(b) Mean spectral acceleration of generated ground motions for zero period shall not be less than A_{0g} .

(c) Mean spectral accelerations of artificially generated acceleration records for 5% damping ratio shall not be less than 90% of the elastic spectral accelerations, $S_{ae}(T)$, defined in 2.4 in the period range between $0.2T_1$ and $2T_1$ with respect to dominant natural period, T_1 , of the building in the earthquake direction considered. In the case where *linear elastic analysis* is performed in the time domain, spectral accelerations defined by Eq.(2.13) shall be considered to define the reduced earthquake ground motion.

2.9.2. Recorded or Simulated Earthquake Ground Motions

Recorded earthquakes or physically simulated ground motions with appropriate source and wave propagation characteristics can be used for seismic analysis to be performed in the time domain. Local site conditions should be appropriately considered in selecting or generating such ground motions. At least three earthquake ground motions shall be selected or generated satisfying all of the conditions given in 2.9.1.

2.9.3. Analysis in the Time Domain

In the case where nonlinear analysis is performed in the time domain, internal force-deformation relationships representing the dynamic behaviour of elements of structural system under cyclic loads shall be defined through relevant literature with proven theoretical and experimental validations. If three ground motions are used the maxima of the results, and if at least seven ground motions are used the mean values of the results shall be considered for design.

2.10. LIMITATION OF DISPLACEMENTS, SECOND ORDER EFFECTS AND SEISMIC JOINTS

2.10.1. Calculation and Limitation of Effective Storey Drifts

2.10.1.1 – The *reduced storey drift*, Δ_i , of any column or structural wall shall be determined by Eq.(2.17) as the difference of displacements between the two consecutive stories.

$$\Delta_i = d_i - d_{i-1} \quad (2.17)$$

In **Eq.(2.17)** d_i and d_{i-1} represent lateral displacements obtained from the analysis at the ends of any column or structural wall at stories i and $(i - 1)$ under reduced seismic loads. However the condition given in **2.7.4.2** as well as the minimum equivalent seismic load condition defined by **Eq.(2.4)** may not be considered in the calculation of d_i and Δ_i .

2.10.1.2 – Effective storey drift, δ_i , of columns or structural walls at the i 'th storey of a building shall be obtained for each earthquake direction by **Eq.(2.18)**.

$$\delta_i = R \Delta_i \quad (2.18)$$

2.10.1.3 – The maximum value of effective storey drifts, $(\delta_i)_{\max}$, obtained for each earthquake direction by **Eq.(2.18)** at columns or structural walls of a given i 'th storey of a building shall satisfy the condition given by **Eq.(2.19)**:

$$\frac{(\delta_i)_{\max}}{h_i} \leq 0.02 \quad (2.19)$$

This limit may be exceeded by 50% in single storey frames where seismic loads are fully resisted by steel frames with joints capable of transferring cyclic moments.

2.10.1.4 – In the case where the condition given by **Eq.(2.19)** is not satisfied at any storey of the building, the seismic analysis shall be repeated with increased stiffness of the structural system. However, even if the condition is satisfied, serviceability of non-structural brittle elements (e.g. façade elements) under effective storey drifts shall be verified by calculation.

2.10.2. Second-Order Effects

Unless a more refined analysis considering the nonlinear behaviour of structural system is performed, second-order effects may be taken into account in accordance with **2.10.2.1**.

2.10.2.1 – In the case where *Second-Order Effect Indicator*, θ_i , satisfies the condition given by **Eq.(2.20)** for the earthquake direction considered at each storey, second-order effects shall be evaluated in accordance with the currently enforced specifications of reinforced concrete or structural steel design.

$$\theta_i = \frac{(\Delta_i)_{\text{ort}} \sum_{j=1}^N w_j}{V_i h_i} \leq 0.12 \quad (2.20)$$

$(\Delta_i)_{\text{ort}}$ shall be determined in accordance with **2.10.1.1** as the average value of reduced storey drifts calculated for i 'th storey columns and structural walls.

2.10.2.2 – In the case where the condition given by **Eq.(2.20)** is not satisfied, seismic analysis shall be repeated with sufficiently increased stiffness of the structural system.

2.10.3. Seismic Joints

Excluding the effects of differential settlements and rotations of foundations and the effects of temperature change, sizes of gaps to be retained in the seismic joints between building blocks or between the old and newly constructed buildings shall be determined in accordance with the following conditions:

2.10.3.1 – Unless a larger value is obtained in accordance with **2.10.3.2** below, sizes of gaps shall not be less than the square root of sum of squares of average storey displacements multiplied by the coefficient α specified below. Storey displacements to be considered are the average values of reduced displacements d_i calculated within a storey at the column or structural wall joints. In the cases where the seismic analysis is not performed for the existing old building, the storey displacements shall not be assumed to be less than those obtained for the new building at the same stories.

(a) $\alpha = R / 4$ shall be taken if all floor levels of adjacent buildings or building blocks are the same.

(b) $\alpha = R / 2$ shall be taken if any of the floor levels of adjacent buildings or building blocks are not the same.

2.10.3.2 – Minimum size of gaps shall be 30 mm up to 6 m height. From thereon a minimum 10 mm shall be added for every 3 m height increment.

2.10.3.3 – Seismic joints shall be arranged to allow the independent movement of building blocks in all earthquake directions.

2.11. SEISMIC LOADS APPLIED TO STRUCTURAL APPENDAGES, ARCHITECTURAL ELEMENTS, MECHANICAL AND ELECTRICAL EQUIPMENT

2.11.1 – Equivalent seismic loads to be applied to structural appendages such as balconies, parapets, chimneys, etc. and to all architectural elements such as façade and partition panels, etc. as well as the seismic loads to be used for the connections of mechanical and electrical equipment to the structural system elements are given by **Eq.(2.21)**.

$$f_e = 0.5 A_o I w_e \left(1 + 2 \frac{H_i}{H_N} \right) \quad (2.21)$$

The seismic load shall be applied horizontally to the mass centre of the element concerned in a direction to result in most unfavourable internal forces. The seismic loads to be applied to non-vertical elements shall be half the equivalent seismic load calculated by **Eq.(2.21)**.

2.11.2 – In the case where the sum of mechanical or electrical equipment weights, as denoted by w_e in **Eq.(2.21)**, exceeds $0.2w_i$ at any i 'th storey, equipment weights and the stiffness properties of their connections to the building shall be taken into account in the earthquake analysis of the building structural system.

2.11.3 – In the case where *floor acceleration spectrum* is determined by appropriate methods to define the peak acceleration at the floor where mechanical or electrical equipment is located, **Eq.(2.21)** may not be applied.

2.11.4 – Twice the seismic load calculated by **Eq.(2.21)** or determined according to **2.11.3** shall be considered for fire extinguishing systems, emergency electrical systems as well as for equipments connecting to infill walls and for their connections

2.12. NON-BUILDING STRUCTURES

Non-building structures permitted to be analysed in accordance with the requirements of this chapter and the corresponding *Structural Behaviour Factors*, (R), to be applied to such structures are given in **Table 2.8**. Applicable *Seismic Load Reduction Factors* shall be determined in accordance with **Eq.(2.3)**. Where applicable, *Building Importance Factors* specified in **Table 2.3** shall be used for non-building structures. However *Live Load Participation Factors* specified in **Table 2.7** shall not be applied. Except snow loads and crane payloads, unreduced weights of all solid and liquid materials stored and mechanical equipment shall be used.

**TABLE 2.8 - STRUCTURAL BEHAVIOUR FACTORS
FOR NON-BUILDING STRUCTURES**

<i>TYPE OF STRUCTURE</i>	<i>R</i>
Elevated liquid tanks, pressurised tanks, bunkers, vessels carried by frames of high ductility level or steel eccentric braced frames	4
Elevated liquid tanks, pressurised tanks, bunkers, vessels carried by frames of nominal ductility level or steel concentric braced frames	2
Cast-in-situ reinforced concrete silos and industrial chimneys with uniformly distributed mass along height ^(*)	3
Reinforced concrete cooling towers ^(*)	3
Space truss steel towers, steel silos and industrial chimneys with uniformly distributed mass along height ^(*)	4
Guyed steel high posts and guyed steel chimneys	2
Inverted pendulum type structures carried by a single structural element with mass concentrated at the top	2
Industrial type steel storage racks	4

^(*) *Analysis of such structures shall be performed in accordance with 2.8 or 2.9 by considering sufficient number of discrete masses defined along the structure.*

2.13. REQUIREMENTS FOR SEISMIC ANALYSIS REPORTS

The following requirements shall apply to the analysis reports that include seismic analysis of buildings:

2.13.1 - Types of irregularities specified in **Table 2.1** shall be evaluated in detail for the building to be designed and, if any, existing irregularities shall be identified.

2.13.2 - The selected structural system of high or nominal ductility level shall be clearly defined with respect to the requirements of **Chapter 3** or **Chapter 4**, and the selection of the applicable R factor from **Table 2.5** shall be explained.

2.13.3 - The selection of the applicable analysis method in accordance with **2.6** shall be clearly explained by considering the seismic zone, building height and structural irregularities involved.

2.13.4 - The following rules shall be applied in the cases where the analysis is performed by computer:

(a) Analysis report shall include three-dimensional illustrations of structural system by indicating the joint and element numbering.

(b) All input data as well as output data including internal forces and displacements shall be included in the analysis report in an easily understandable format.

(c) The title, author and the version of the computer software used in the analysis shall be clearly indicated.

(d) When requested by the approval authority, theory manual and user's guide of the computer software shall be included in the analysis report.

2.14. INSTALLATION OF STRONG MOTION RECORDERS

Upon endorsement by the Ministry of Public Works and Settlement, strong ground motion accelographs shall be permitted to be installed by the ministry or university institutions on the public, private or corporate buildings and other structures for the purpose of recording the strong earthquake motions, and owners or operators of buildings or structures shall be responsible from the safety of such instruments.

APPENDIX

Relevant clauses from

CHAPTER 3 – EARTHQUAKE RESISTANT DESIGN REQUIREMENTS FOR REINFORCED CONCRETE BUILDINGS

3.0. NOTATION

- ΣA_e = Effective shear area at any storey for the earthquake direction considered
 ΣA_g = Sum of section areas of structural elements at any storey behaving as structural walls in the direction parallel to the earthquake direction considered
 ΣA_k = Sum of masonry infill wall areas (excluding door and window openings) at any storey in the direction parallel to the earthquake direction considered
 A_w = Effective web area of column cross section (excluding protrusions in the direction perpendicular to the earthquake direction)
 ΣA_w = Sum of effective web areas of column cross sections, A_w 's at any storey

CHAPTER 6 – FOUNDATION SOILS AND EARTHQUAKE RESISTANT DESIGN REQUIREMENTS FOR FOUNDATIONS

6.2. DETERMINATION OF SOIL CONDITIONS

6.2.1. Soil Groups and Local Site Classes

6.2.1.1 – Soil groups and local site classes to be considered as the bases of determination of local soil conditions are given in **Table 6.1** and **Table 6.2**, respectively. Values of soil parameters in **Table 6.1** are to be considered as standard values given for guidance only in determining the soil groups.

6.2.1.2 – Soil investigations based on appropriate site and laboratory tests are mandatory to be conducted for below given buildings with related reports prepared and attached to design documents. Soil groups and local site classes to be defined in accordance with **Table 6.1** and **Table 6.2** shall be clearly indicated in reports.

(a) All buildings with total height exceeding 60 m in the first and second seismic zones,

(b) Irrespective of the building height, buildings in all seismic zones with Building Importance Factor of $I=1.5$ and $I=1.4$ according to **Table 2.3** of **Chapter 2**.

6.2.1.3 – Regarding the buildings outside the scope of above given **6.2.1.2**, in the first and second seismic zones, available local information or observation results shall be included or published references shall be quoted in the seismic analysis reports to identify the soil groups and local site classes in accordance with **Table 6.1** and **Table 6.2**.

6.2.1.4 – In the first and second seismic zones, horizontal bedding parameters as well as horizontal and vertical load carrying capacities of piles under seismic loads in Group (C) and (D) soils according to **Table 6.1** shall be determined on the basis of soil investigations including in-situ and laboratory tests.

TABLE 6.1 – SOIL GROUPS

<i>Soil Group</i>	<i>Description of Soil Group</i>	<i>Stand. Penetr. (N/30)</i>	<i>Relative Density (%)</i>	<i>Unconf. Compres. Strength (kPa)</i>	<i>Shear Wave Velocity (m/s)</i>
(A)	1. Massive volcanic rocks, unweathered sound metamorphic rocks, stiff cemented sedimentary rocks	—	—	> 1000	> 1000
	2. Very dense sand, gravel...	> 50	85–100	—	> 700
	3. Hard clay, silty clay.....	> 32	—	> 400	> 700
(B)	1. Soft volcanic rocks such as tuff and agglomerate, weathered cemented sedimentary rocks with planes of discontinuity.....	—	—	500–1000	700–1000
	2. Dense sand, gravel.....	30–50	65–85	—	400–700
	3. Very stiff clay, silty clay..	16–32	—	200–400	300–700
(C)	1. Highly weathered soft metamorphic rocks and cemented sedimentary rocks with planes of discontinuity	—	—	< 500	400–700
	2. Medium dense sand and gravel.....	10–30	35–65	—	200–400
	3. Stiff clay, silty clay.....	8–16	—	100–200	200–300
(D)	1. Soft, deep alluvial layers with high water table.....	—	—	—	< 200
	2. Loose sand.....	< 10	< 35	—	< 200
	3. Soft clay, silty clay.....	< 8	—	< 100	< 200

TABLE 6.2 – LOCAL SITE CLASSES

<i>Local Site Class</i>	<i>Soil Group according to Table 6.1 and Topmost Layer Thickness (h_1)</i>
Z1	Group (A) soils Group (B) soils with $h_1 \leq 15$ m
Z2	Group (B) soils with $h_1 > 15$ m Group (C) soils with $h_1 \leq 15$ m
Z3	Group (C) soils with $15 \text{ m} < h_1 \leq 50$ m Group (D) soils with $h_1 \leq 10$ m
Z4	Group (C) soils with $h_1 > 50$ m Group (D) soils with $h_1 > 10$ m

In the case where the thickness of the topmost soil layer under the foundation is less than 3 m, the layer below may be considered as the topmost soil layer indicated in Table 6.2.