CHAPTER 2

MINIMUM DESIGN LOADS AND LATERAL FORCES FOR BUILDINGS AND OTHER STRUCTURES

SEC. 2.0 GENERAL

All structures regulated by this Code shall be designed for the loads and lateral forces specified in this Chapter as a minimum. Larger loads and lateral forces may be required by the site specific conditions as determined by the Building Official or by the Structural Engineer of record.

SEC. 2.1 GRAVITY LOADS

2.1.1 Definitions

(a) The following definitions give the meaning of certain terms used in this chapter.

Dead Load is the vertical load due to the weight of all permanent structural and nonstructural components of a building, such as walls, floors, roofs and fixed service equipment.

Live Load is the load superimposed by the use and occupancy of the building not including wind load, earthquake load or dead load. Where application of live load results in impact, such impact effects shall be considered in the design.3

Load Duration is the period of continuous application of a given load, or the aggregate of periods of intermittent application of the same load.

(b) Critical Distribution of Live Loads. Where structural members are arranged so as to create continuity, the loading conditions which would cause maximum shear and bending moments along the member shall be investigated.

(c) Stress Increases. Allowable stresses and soil-bearing values specified in this code for working stress design may be increased by the amounts provided for in the pertinent Chapters of this Code for different materials when considering wind or earthquake forces either acting alone or in combination with dead and live loads. No increase will be allowed for dead and live load combinations.

Where strength or plastic design methods are used, increases in stresses do not apply.

(d) Load Factors. Load factors for ultimate strength design of concrete and plastic design of steel shall be as indicated in the appropriate chapters.

(e) Load Combinations. Every building component shall be provided with strength adequate to resist the most critical effect resulting from the following combination of loads (floor live load shall not be included where its inclusions results in lower stresses in the member under investigation) :

1. Dead plus floor live plus roof live load

2. Dead plus floor

3. Dead plus floor live plus seismic loads

4. Dead plus seismic loads

Crane hook loads need not be combined with roof live load nor with wind load.

2.1.2 Floor Design

2.1.2.1 General. Floors shall be designed for the unit loads set forth in Table No. 2.1.2A, 2.1.2B and 2.1.2C. These loads shall be taken as the minimum live loads of horizontal projection to be used in the design of buildings for the occupancies listed, and loads at least equal shall be assumed for uses not listed in this section but which create or accommodate similar loadings.

EXCEPTION : In designing floors to be used for industrial or commercial purposes, the actual live load caused by the use to which the building or part thereof is to be put shall be used in the design of such building or part thereof, and special provisions shall be made for machine or apparatus loads when such machine or apparatus would cause a greater load than specified for such use.

2.1.2.2 Distribution of Uniform Floor Loads. Where uniform floor loads are involved, consideration may be limited to full dead load on all spans in combination with full live load on adjacent spans and on alternate spans.

2.1.2.3 Concentrated Loads. Provision shall be made in designing floors for a concentrated load as set forth herein, wherever this load upon an otherwise unloaded floor would produce stresses greater than those caused by the uniform load required thereof.

1. Elevator machine room grating, 1300 N on area of 2500 mm^2

2. Finish light floor plate, 900 N on area of 650 mm^2

3. Floors other than those above, 9000 N on area of 750 mm x 750 mm

4. Scuttles, skylights and accessible ceilings, 9000 N on an area of 750 mm x 750 mm

Provision shall be made in areas where vehicles are used or stored for concentrated loads consisting of two or more loads spaced 1.50m. nominally on center without uniform live loads. Each load shall be 40 percent of the gross weight of the maximum size vehicle to be accommodated. The condition of concentrated or uniform live load producing the greater stresses shall govern. Garages for the storage of private pleasure cars shall have the floor system designed for a concentrated wheel load of not less 8900 N without uniform live loads. The condition of concentrated or uniform live load producing the greater stresses shall govern.

Provision shall be made for special vertical and lateral loads as set forth in Table No. 2.1.2B.

2.1.2.4 Partition Loads. Floors in office buildings and in other buildings where partition locations are subject to change shall be designed to support in addition to all other loads, a uniformly distributed dead load equal to 1000 Pa.

2.1.2.5 Live Loads. The live loads for which each floor or roof or any part thereof of a building to be designed shall be as provided in Table No. 2.1.2A, Table No. 2.1.2B and Table No. 2.1.2C

2.1.3 Roof Design

2.1.3.1 General. Roof shall sustain, within the stress limitations of this code, all "dead load" plus unit "live loads" as set forth in Table No. 2.1.2A. The live loads shall be assumed to act vertically upon the area projected upon a horizontal plane.

2.1.3.2 Distribution of Loads. Where uniform roof loads are involved in the design of structural members arranged so as to create continuity, considerations may be limited to full dead loads on all spans, in combination with full live loads on adjacent spans and on alternate spans.

2.1.3.3 Unbalanced Loading. Unbalanced loads shall be used where such loading will result in larger members or connections. Trusses and arches shall be designed to resist the stresses caused by unit live loads on one half of the span if such loading results in reverse stresses, or stresses greater in any portion than the stresses produced by the required unit live load upon the entire span. For roofs whose structure is composed of a stressed shell, framed or solid, wherein stresses caused by any point loading are distributed throughout the area of the shell, the requirements for unbalanced unit live load design may be reduced by 50 percent.

2.1.3.4 Special-Purpose Roofs. Roofs to be used for special purposes shall be designed for appropriate loads as approved by the building official.

Greenhouse roof bars, purlins and rafters shall be designed to carry a 445N minimum concentrated load in addition to the live load.

2.1.3.5 Water Accumulation. All roofs shall be designed with sufficient slope or camber to assure adequate drainage after the long-time deflection from dead load or shall be designed to support maximum loads including possible ponding of water due to deflection. See Section 2.1.5 for deflection criteria.

2.1.4 Reduction of Live Loads

2.1.4.1 The design live load determined using the unit live loads as set forth in Table 2.1A, 2.1B and 2.1C may be reduced on any member supporting more than 14 square meters, including flat slabs, except for floors in places of public assembly and for live loads greater than 4800 Pa., in accordance with the following formula :

$$R = r\,(A - 14) \qquad 1.1$$

The reduction shall not exceed 40 percent for members receiving load from one level only, 60 percent for other members, nor R, as determined by the following formula :

$$R = 23.1\ (1 + D/L) \qquad 1.2$$

WHERE :

R = Reduction in percent
r = Rate of reduction equal to 0.86 percent for floors
A = Area of floor or roof supported by the member in sq. m.
D = Dead load per square meter of area supported by the members
L = Unit live load per square meter of area supported by the members

For storage live loads exceeding 4800 Pa. no reduction shall be made except that design live loads on columns may be reduced 20 percent.

The live load reduction shall not exceed 40 percent in garages for the storage of private pleasure cars having a capacity of not more than nine passengers per vehicle.

2.1.5 Deflection

2.1.5.1 The deflection of any structural members shall not exceed the values set forth for different materials in Chapters 3 through 6 of this Code. The deflection criteria representing the most restrictive condition shall apply. Deflection criteria for materials not specified shall be developed in a manner consistent with the provisions of this section. See Section 2.1.3.5 for camber requirements. Span tables for light wood frame construction as specified in Chapter 3 shall conform to the design criteria contained therein, except that where the dead load exceeds 50 percent of the live load, Table No. 2.1D shall govern.

2.1.6 Special Design

2.1.6.1 General. In addition to the design loads specified in this chapter, the design of all structures should consider the special loads set forth in Table No. 2.1B in this section.

2.1.6.2 Retaining Walls. Retaining walls shall be designed to resist the lateral pressure of the retained material in accordance with accepted engineering practice. Walls retaining drained earth may be designed for pressure equivalent to that exerted by a fluid weighing not less than **500 kg/m^3**

and having a depth equal to that of the retained earth. Any surcharge shall be in addition to the equivalent fluid pressure.

2.1.6.3 Heliport and Helistop Landing Areas. In addition to other design requirements of this chapter, heliport and helistop landing or touch-down areas shall be designed for the maximum stress induced by the following :

1. Dead load plus actual weight of the helicopter.

2. Dead load plus a single concentrated impact load covering 93,000 mm^2 of 0.75 times the fully loaded weight of the helicopter if it is equipped with hydraulic-type shock absorbers, or 1.5 times the fully loaded weight of the helicopter if it is equipped with a rigid or skid-type landing gear.

3. The dead load plus a uniform live load of 4800 Pa. The required live load may be reduced in accordance with the formula in Section 2.1.4.

2.1.7 Walls and Structural Framing

(a) General. Walls and structural framing shall be erected true and plumb in accordance with the design.

(b) Interior Walls. Interior walls, permanent partitions, and temporary partitions which exceed 1.5 m in height shall be designed to resist all loads to which they are subjected but not less than a force of 250 Pa. applied perpendicular to the walls. The deflection of such walls under a load of 250 Pa. shall not exceed 1/240 of the span for walls with brittle finishes and 1/120 of the span for walls with flexible finishes. See Sec. 2.2 for earthquake design requirements where such requirements are more restrictive.

EXCEPTION : Flexible, folding or portable partitions are not required to meet the load and deflection criteria but must be anchored to the supporting structure to meet the provisions of this code.

2.1.8 Anchorage of Concrete or Masonry Walls

(a) Concrete or masonry walls shall be anchored to all floors and roofs which provide lateral support for the wall. Such anchorage shall provide a positive direct connection capable of resisting the horizontal forces specified in this chapter or a minimum force of 3000 N/m of wall, whichever is greater. Walls shall be designed to resist bending between anchors where the anchor spacing exceeds 1.20 m. Required anchors in masonry walls of hollow units or cavity walls shall be embedded in a reinforced grouted structural element of the wall. See Chapter 6.

2.1.9 Walkway

A walkway not less than 1.20 m. wide shall be maintained on the sidewalk in front of the building site during construction, alteration or demolition unless the public agency having jurisdiction authorizes the sidewalk to be fenced and closed. Adequate signs and railings shall be provided to direct pedestrian traffic.

The walkway shall be capable of supporting a uniform live load of 7200 Pa.

2.1.10 Pedestrian Canopies

(a) Canopies. The protective canopy shall have a clear height of 2.4 m above the walkway. The roof shall be tightly sheathed. The sheathing shall be 50 mm. nominal wood planking or equal. Every canopy shall have a solid fence built along its entire length in the construction side.

If materials are stored or work is done on the roof of the canopy, the street sides and ends of the canopy roof shall be protected by a tight curb board not less than 300 mm high and a railing not less than 1 m.

The entire structure shall be designed to carry the loads to be imposed on it, provided the live load shall be not less than 7200 Pa.

2.1.11 Gridirons

The lead block wall must be provided with an adequate strongback or lateral track to offset torque.

TABLE 2.1A – UNIFORM AND CONCENTRATED LOADS

Use of Occupancy: Category	Use of Occupancy: Description	Uniform Load[1] Pa	Concentrated Load N
1. Armories		7200	0
2. Assembly areas[4] and auditorium and balconies therewith*	Fixed seating areas	2400	0
	Movable seating and other areas	4800	0
	Stage areas and enclosed platforms	6000	0
3. Cornices, marquees and residential balconies		3000	0 [8]
4. Exit facilities[5]		4800	0
5. Garages	General storage and /or repair	4800	[3]
	Private pleasure car storage	2400	[3]
6. Hospitals	Wards and rooms	2000	4500[2]
7. Libraries	Reading rooms	3000	4500[2]
	Stack rooms	6000	6700[2]
8. Manufacturing	Light	3600	8900[2]
	Heavy	6000	13400[2]
9. Offices		2400	8900[2]
10. Printing Plants	Press rooms	7200	11200[2]
	Composing and linotype rooms	4800	8900[2]
11. Residential[6]		2000	0 [8]
12. Rest rooms[7]			
13. Reviewing stands, grandstands and bleachers		4800	0
14. Roof deck	Same as area served or for the type of occupancy accommodated		
15. Schools	Classrooms	2000	4500[2]
16. Sidewalks and driveways	Public access	12000	[3]
17. Storage	Light	6000	
	Heavy	12000	
18. Stores	Retail	3600	8900[2]
	Wholesale	4800	13400[2]
19. Low cost housing unit[9]		1500	0 [8]

FOOTNOTES FOR TABLE 2.1A

[1] See Section 2.1.4 for live load reductions.
[2] See Section 2.1.2.3, first paragraph, for area of load application.
[3] See Section 2.1.2.3, second paragraph, for concentrated loads.
[4] Assembly area include such occupancies as dance halls, drill rooms, gymnasiums, playgrounds, plazas, terraces and similar occupancies which are generally accessible to the public.
[5] Exit facilities shall include such uses as corridors serving an occupant load of 10 or more persons, exterior exit balconies, stairways, fire escapes and similar uses.
[6] Residential occupancies include private dwellings, apartments and hotel guest rooms.
[7] Rest room loads shall be not less than the load for the occupancy with which they are associated, but not to exceed 2400 Pa.
[8] Individual stair treads shall be designed to support a 1300 N concentrated load placed in a position which would cause maximum stress. Stair stringers may be designed for the uniform load set forth in the table.
[9] Total floor area of a unit shall not exceed 60 m^2.

TABLE 2.1B – SPECIAL LOADS[1]

USE		VERTICAL LOAD	LATERAL LOAD
Category	Description	(Pa. Unless Otherwise noted)	
1. Construction, public access at the site (live load	Walkway, See Sec. 2.1.9	7200	
	Canopy, See Sec. 2.1.10	7200	
2. Grandstands, reviewing stands and bleachers (live load)	Seats and footboards	1750[2]	See Footnote 3
3. Stage accessories, see Sec. 2.1.11 (live load)	Gridirons and fly galleries	3600	
	Loft block wells[4]	3650	3650
	Head block wells and sheave beams[4]	3650	3650
4. Ceiling framing (live load)	Over stages	1000	
	All uses except over stages	500[5]	
5. Partitions and interior walls, see Sec. 2.1.7 (live load)			250
6. Elevators and dumbwaiters (dead and live load)		2 by Total loads	
7. Mechanical and electrical equipment (dead load)		Total load	
8. Cranes (dead and live load)[6]	Total load including Impact increase	1.25 by Total load[6]	0.10 by Total load[7]
9. Balcony railings, guardrails and handrails	Exit facilities serving an occupant load greater than 50		750 [8]
	Other		300 [8]
10. Storage racks	Over 2.4 m.	Total loads[9]	See Chapter 2

[1]The tabulated loads are minimum loads. Where other vertical loads required by this code or required by the design would cause greater stresses, they shall be used.

[2] Newton per linear meter, N/m

[3] Lateral sway bracing loads of 350 N/m parallel and 150 N/m perpendicular to seat and footboards.

[4] All loads are in N/m. Head block wells and sheave beams shall be designed for all loft block well loads tributary thereto. Sheave blocks shall be designed with a factor of safety of five.

[5] Does not apply to ceilings which have sufficient total access from below, such that access is not required within the space above the ceiling. Does not apply to ceilings if the attic areas above

the ceiling are not provided with access. This live load need not be considered acting simultaneously with other live loads imposed upon the ceiling framing or its supporting structure.

[6] The impact factors included are for cranes with steel wheels riding on steel rails. They may be modified if substantiating technical data acceptable to the building official are submitted. Live loads on crane support girders and their connections shall be taken as the maximum crane wheel loads. For pendant-operated traveling crane support girders and their connections, the impact factors shall be 1.10.

[7] This applies in the direction parallel to the runway rails (longitudinal). The factor for forces perpendicular to the rail is 0.20 x the transverse traveling loads (trolly, cab, books and lifted loads). Forces shall be applied at top of rail and may be distributed among rails of multiple rail cranes and shall be distributed with due regard for lateral stiffness of the structures supporting these rails.

[8] A load per linear meter to be applied horizontally at right angles to the top rail.

[9] Vertical members of storage racks shall be protected from impact forces of operating equipment or racks shall be designed so that failure of one vertical member will not cause collapse of more than the bay or bays directly supported by that member.

TABLE 2.1C - MINIMUM ROOF LIVE LOADS

	TRIBUTARY LOADED AREA FOR ANY STRUCTURAL MEMBER		
Roof Slope	0 to 20 sq.m.	21 to 60 sq.m.	Over 60 sq.m.
1. Flat or rise less than 1 vertical to 3 horizontal; Arch or dome with rise less 1/8 of span	1000 Pa	800 Pa	600 Pa
2. Rise 1 vertical per 3 horizontal to less than 1 horizontal; Arch or dome with rise 1/8 of span to less than 3/8 of span	800 Pa	700 Pa	600 Pa
3 Rise 1 vertical to 1 horizontal; Arch or dome with rise 3/8 of span or greater	600 Pa	600 Pa	600 Pa
4 Awnings, except cloth covered	250 Pa	250 Pa	250 Pa
5. Green Houses, lathhouses and agricultural buildings	500 Pa	500 Pa	500 Pa

TABLE 2.1D - MAXIMUM ALLOWABLE DEFLECTION FOR STRUCTURAL MEMBERS

TYPE OF MEMBER	MEMBER LOADED WITH LL ONLY	MEMBER LOADED WITH LL + K(DL)
Roof Member Supporting Plaster or Floor Member	L/360	L/240

[1] Sufficient slope or camber shall be provided for flat roofs.

LL = Live Load
DL = Dead Load
K = Factor as determined by Table 2.1E.
L = Length of member in same units as deflection.

TABLE 2 1E - VALUE OF "K"

WOOD		REINFORCED CONCRETE[2]	STEEL
Unseasoned	Seasoned [1]	$2 - 1.2\,(A'_s/A_s) \geq 0.6$	0
1.0	0.5		

[1] Seasoned lumber is lumber having a moisture content of less than 16 percent at the time of installation and used under dry conditions of use such as in most covered structures.

[2] A's = Area of compressive reinforcing steel in flexural members

As = Area of non-prestressed tensile reinforcing steel in flexural members

SEC. 2.2 LATERAL FORCES

2.2.0 General

Every structure and every portion thereof shall be designed and constructed to sustain appropriate combinations of vertical (dead and live) loads and lateral forces due to wind or earthquake, as specified in this chapter. Detailing requirements and limitations prescribed for resistance to earthquake forces shall be followed even if wind effects are controlling. Impact loads shall be considered where they occur.

2.2.1 Earthquake Forces

2.2.1.1 General. *Every structure and every portion thereof shall, as a minimum, be designed and constructed to resist the appropriate combinations of vertical dead and live loads, and wind as provided in Section 2.3 as well as for combinations including the effects of seismic ground motions as provided in this section.*

2.2.1.1.1 *Dead, live and wind loads shall be in accordance with the applicable provisions of Section 2.1 of this Code. Earthquake loads shall be considered in combination with dead loads and live loads as described in Sec. 2.2.5.1.3.*

2.2.1.1.2 *The effects of vertical accelerations must be considered for structures in Seismic Zone 4.*

2.2.1.2 *Allowable working stresses for ordinary or non-seismic construction will be increased by one-third for load combinations involving earthquake loading, provided the required section or area computed on this basis is not less than that required for vertical loading, without the one-third increase. Working stresses for reinforced masonry construction shall be as given in Chapter 6, Masonry. The one-third increase in stresses does not apply when strength design or plastic design methods are used nor as required by Section 4.5.6.*

2.2.1.3 A continuous load path, or paths, with adequate strength and stiffness shall be provided which will transfer all forces from the place of application to the resisting elements.

2.2.1.4 The basis for the seismic design shall be stated on the structural drawings. The statement shall include: (1) the governing edition of the building code; (2) the total base shear coefficient used for seismic design; and (3) a description of the lateral force resisting system, as defined in these requirements.

2.2.2 Definitions

Base is the level at which the earthquake motions are considered to be imparted to the structure or the level at which the structure, as a dynamic vibrator, is supported.

Base Shear, V, is the total designed lateral force or shear at the base of a structure.

Bearing Wall System is a structural system without a complete vertical load carrying space frame. See Sec. 2.2.4.6.1.

Boundary Element is an element at edges of opening or at perimeters of shear walls or diaphragms.

Braced Frame is an essentially vertical truss system of the concentric or eccentric type which is provided to resist lateral forces.

Building Frame System is an essentially complete space frame which provides supports for gravity loads. See Sec. 2.2.4.6.2 .

Collector is a member or an element provided to transfer lateral forces from a portion of a structure to vertical elements of the lateral force resisting system.

Concentric Braced Frame is a braced frame in which the members are subjected primarily to axial forces.

Diaphragm is a horizontal or nearly horizontal system acting to transmit lateral forces to the vertical resisting elements. The term "diaphragm" includes horizontal bracing systems.

Diaphragm Chord is the boundary element of a diaphragm or a shear wall which is assumed to take axial stresses analogous to the flanges of a beam.

Diaphragm Strut (drag strut, tie, collector) is the element of a diaphragm parallel to the applied load which collects and transfers diaphragm shear to vertical resisting elements or distributes loads within the diaphragm. Such members may take axial tension or compression.

Drift; see STORY DRIFT.

Dual System is a combination of a Special or Intermediate Moment Resisting Space Frame and Shear Walls or Braced Frames designed in accordance with the criteria of Sec. 2.2.4.6.4 .

Eccentric Braced Frame (EBF) is a steel braced frame designed in conformance with Chapter 4, Part 3.

Essential Facilities are those structures which are necessary for emergency post-earthquake operations.

Flexible Element or system is one whose deformation under lateral load is significantly larger than adjoining parts of the system. Limiting ratios for defining specific flexible elements are set forth in Sections 2.2.5.3.1(2), 2.2.5.6.1, or 2.2.7.2.3.

Horizontal Bracing System is a horizontal truss system that serves the same function as a diaphragm.

Intermediate Moment Resisting Space Frame (IMRSF) is a concrete space frame designed in conformance with Sec. 5.21.9 of this code.

Lateral Force Resisting System is that part of the structural system assigned to resist lateral forces.

Moment Resisting Space System is a space frame in which the members and joints are capable of resisting forces primarily by flexure.

Ordinary Moment Resisting Space Frame is moment resisting space frame not meeting special detailing requirements for ductile behavior.

Orthogonal Effects are the effects on the structure due to earthquake motions acting in directions other than parallel to the direction of resistance under consideration.

P-delta Effect is the secondary effect on shears and moments of frame members induced by the vertical loads acting on the laterally displaced building frame.

Platform is the lower rigid portion of a structure having a vertical combination of structural systems for use in Sec. 2.2.4.8.1

Shear Wall is a wall designed to resist lateral forces parallel to the plane of the wall (sometimes referred to as a vertical diaphragm or a structural wall).

Soft Story, as used in this code, is one in which the lateral stiffness is less than 70 percent of the stiffness of the story above.

Soil-Structure Resonance is the coincidence of the natural period of a structure with the dominant frequency in the ground motion.

Space Frame is a three-dimensional structural system without bearing walls composed of members interconnected so as to function as a complete self contained unit with or without the aid of horizontal diaphragms or floor bracing systems.

Special Moment Resisting Space Frame (SMRSF) is a moment resisting space frame specially detailed to provide ductile behavior and complying with the requirements given in Sec. 5.21 or Chapter 4, Part 3 of this code.

Story is the space between levels. Story x is the story below level x.

Story Drift is the displacement of one level relative to the level above or below.

Story Drift Ratio is the story drift divided by the story height.

Story Shear, V_x, is the summation of design lateral forces above the story under consideration.

Strength is the usable capacity of a structure or its members to resist loads within the deformation limits prescribed in this document.

Structure is an assemblage of framing members designed to support gravity loads and resist lateral forces. Structures may be categorized as building structures or non-building structures.

Tower is the upper flexible portion of a structure having a vertical combination of structural systems for use in Section 2.2.4.8.1.

Vertical Load Carrying Space Frame is a space frame designed to carry all vertical (gravity) loads.

Weak Story is one in which the story strength is less than 80 percent of that of the story above.

2.2.3 Symbols and Notations

The following symbols and notations apply to the provisions of this Chapter:

A_c = The combined effective area, in sq. m, of the shear walls in the first story of the structure, as determined from Formula (2-4).

A_e = The effective horizontal cross-sectional area, in sq. m, of a shear wall in the first story of the structure, for use in Formula (2-4).

A_x = The torsional amplification factor at level x, as determined from Formula (2-9).

C = Numerical coefficient specified in Sec. 2.2.5.2.1.

C_p = Numerical coefficient specified in Sec. 2.2.7 and given in Table 2.2H.

C_t = Numerical coefficient given in Sec. 2.2.5.2.2.1.

D_e = The length, in m, of a shear wall element in the first story in the direction parallel to the applied forces, for use in Formula (2-4).

δ_i = Horizontal displacement at Level i relative to the base due to applied lateral forces, f_i, for use in Formula (2-5).

f_i = Lateral force at Level i for use in Formula (2-5).

F_i, F_n, F_x = Lateral force applied to Level i, n, or x, respectively, for use in Formulas (2-6) and (2-11) and as determined from Formula (2-8).

F_p = Lateral forces on a part of the structure, as determined from Formula (2-10).

F_t = That portion of the base shear, V, considered concentrated at the top of the structure in addition to F_n, for use in Formulas (2-6), (2-8), and (2-11).

g = Acceleration due to gravity, for use in Formula (2-5).

h_i, h_n, h_x = Height in m, above the base to Level i, n, or x, respectively, for use in Formula (2-8).

I = Importance factor given in Table 2.2D.

Level i = Level of the structure referred to by the subscript i. i=1 designates the first level above the base.

Level n = That level which is uppermost in the main portion of the structure.

Level x = That level which is under design consideration. x=1 designates the first level above the base.

R_w = Numerical coefficient given in Tables 2.2G and 2.2I.

S = Site coefficient for soil characteristics given in Table 2.2B.

T = Fundamental period of vibration, in seconds, of the structure in the direction under consideration, as determined from Formula (2-3) or Formula (2-5).

V = The total design lateral force or shear at the base, as determined from Formula (2-1).

V_x = The design story shear in story x, given in Sec. 2.2.5.5.1.

W = The total seismic dead load defined in Sec. 2.2.5.1.3.

W_i, W_x = That portion of W which is located at or is assigned to Level i or x, respectively, for use in Formulas(2-8) and (2-11).

W_{px} = The weight of the diaphragm and the elements tributary thereto at Level x, including applicable portions of other loads defined in Sec. 2.2.5.1.3.

W_p = The weight of an element or component, for use in Formula (2-10).

Z = Seismic zone factor given in Table 2.2A.

2.2.4 Criteria Selection

2.2.4.1 Basis for Design. The minimum design seismic forces shall be those determined in accordance with the static lateral force procedure of Sec. 2.2.5 except as modified by Sec. 2.2.6.5.3.

2.2.4.2 Seismic Zones. Each site shall be assigned to a seismic zone: in accordance with Figure 2.2-B. Each structure shall be assigned a zone factor, Z, in accordance with Table 2.2A.

2.2.4.3 Site Geology and Soil Characteristics. Soil profile type and site coefficient, S, shall be established in accordance with Table 2.2B.

2.2.4.4 Occupancy Categories. For purposes of earthquake resistant design, each structure shall be placed in one of the occupancy categories listed in Table 2.2C. Table 2.2D lists importance factor, I. Review requirements for each category are given in Sec. 1.3.2.

2.2.4.5 Configuration Requirements. Each structure shall be designated as being structurally regular or irregular.

2.2.4.5.1 Regular Structures. Regular structures have no significant physical discontinuities in plan or vertical configuration or in their lateral force resisting systems such as the irregular features described in Sec. 2.2.4.5.2 below.

2.2.4.5.2 Irregular Structures. Irregular structures have significant physical discontinuities in configuration or in their lateral force resisting systems. Irregular features include, but are not limited to, those described in Tables 2.2E and 2.2F.

2.2.4.5.2.1 Vertical Irregularity. Structures having one or more of the features listed in Table 2.2E shall be designated as having a vertical irregularity.

EXCEPTION: Where no story drift ratio under design lateral load is greater than 1.3 times the story drift ratio of the story above, the structure may be deemed to not have irregularities of Types A or B in Table 2.2E. The drift ratio relationship for the top two stories need not be considered. The story drifts for this determination may be calculated neglecting torsional effects.

2.2.4.5.2.2 Plan Irregularity. Structures having one or more of the features listed in Table 2.2F shall be designated as having a plan irregularity.

2.2.4.6 Structural Systems. Structural Systems shall be classified as one of the types listed in Table 2.2G and defined below.

2.2.4.6.1 Bearing Wall System. A structural system without a complete vertical load carrying space frame. Bearing walls or bracing systems provide support for gravity loads. Resistance to lateral load is provided by shear walls or braced frames.

2.2.4.6.2 Building Frame System. A structural system with essentially complete space frame providing support for gravity loads. Resistance to lateral load is provided by shear walls or braced frames.

2.2.4.6.3 Moment Resisting Frame System. A structural system with an essentially complete space frame providing support for gravity loads. Moment resisting space frames provide resistance to lateral load primarily by flexural action of members.

2.2.4.6.4 Dual System. A structural system with the following features:

(1) An essentially complete space frame providing support for gravity loads.

(2) Resistance to lateral load is provided by:

(a) A specially detailed moment resisting space frame (concrete or steel) which is capable of resisting at least 25 percent of the base shear.

(b) Shear walls or braced frames capable of resisting at least 75% of the base shear.

(3) The two systems shall be designed to resist the total lateral load in proportion to their relative rigidities.

2.2.4.6.5 Undefined Structural System. A structural system not listed in Table 2.2G.

2.2.4.6.6 Non-Building Structural System. A structural system conforming to Section 2.2.9.

2.2.4.7 Height Limits. Height limits for the various structural systems in Seismic Zones 3 and 4 are given in Table 2.2G.

EXCEPTION: Regular structures may exceed these limits by not more than 50 percent under the following conditions:

a. Unoccupied structures which are not accessible to the general public.

b. Other structures when technical data is submitted per Sec. 2.2.4.9.2 and the special review requirements of Sec. 1.3.2 are satisfied.

2.2.4.8 Selection of Lateral Force Procedure. Any structure may be, and certain structures defined below shall be, designed using the dynamic lateral force procedures of Sec. 2.2.6.

2.2.4.8.1 The static lateral force procedure of Sec. 2.2.5 may be used for the following structures:

(1) Regular structures under 70 m in height with lateral force resistance provided by systems listed in Table 2.2G except where Sec. 2.2.4.8.2(4) applies.

(2) Irregular structures not more than 5 stories nor 20 m in height.

(3) Structures having a tower supported on a platform conforming to the following:

(a) Both portions of the structure considered separately can be classified as regular.

(b) The average story stiffness of the platform is at least ten times the average story stiffness of the tower.

(c) The period of the entire structure is not greater than 1.1 times the period of the tower considered as separate structure fixed at the base.

2.2.4.8.2 The dynamic lateral force procedures of Sec. 2.2.6 shall be used for all other structures including the following:

(1) Structures 70m or more in height except as permitted by Sec. 2.2.4.8.1(1).

(2) Structures having a stiffness, weight or geometric vertical irregularity of Type A, B, or C as defined in Table 2.2E or structures having irregular features not described in either Table 2.2E or 2.2F except as permitted by Sec. 2.2.5.3.1.

(3) Structures over 5 stories or 20 m in height in Seismic Zones 3 and 4 not having the same structural system throughout their height except as permitted by Sec. 2.2.5.3.1.

(4) Structures, regular or irregular, located on Soil Profile Type 4 which have a period greater than 0.7 seconds. The analysis shall include the effects of the soils at the site and shall conform to Sec. 2.2.6.2.4.

2.2.4.9 System Limitations. Limits are placed on the use of some structural systems in accordance with the requirements of this section.

2.2.4.9.1 Structures other than wood frame structures with discontinuity in capacity, vertical irregularity Type E as defined in Table 2.2E, shall not be permitted over two stories or 10 m in height where the "weak" story has a calculated strength of less than 65 percent of the story above.

EXCEPTION: Where the "weak" story is capable of resisting a total lateral seismic force of 3(Rw/8) times the design force prescribed in Sec. 2.2.5.

2.2.4.9.2 Undefined Structural Systems. Undefined structural systems shall be shown by technical and test data which establish the dynamic characteristics and demonstrate the lateral force resistance and energy absorption capacity to be equivalent to systems listed in Table 2.2G for equivalent R_w values.

2.2.4.9.3 All structures having irregular features described in Table 2.2E or 2.2F shall be designed to meet the additional requirements of those sections referenced in the tables.

2.2.4.10 Alternative Procedures. Alternative lateral force procedures using rational analyses based on well established principles of mechanics may be used in lieu of those prescribed in these recommendations.

2.2.5 Minimum Design Lateral Forces and Related Effects

2.2.5.1 General

2.2.5.1.1 Seismic forces may come from any horizontal direction.

2.2.5.1.2 The design seismic forces may be assumed to act non-currently in the direction of each principal axis of the structure, except as required by Sec. 2.2.8.1.3.

2.2.5.1.3 Seismic dead load, W, is the total dead load and applicable portions of other loads listed below.

(1) In storage and warehouse occupancies, a minimum of 25 percent of the floor live load shall be applicable.

(2) Where an allowance for partition load is included in the floor design, the applicable portion of the load shall be not less than 0.5 KPa.

(3) Total weight of permanent equipment shall be included.

2.2.5.2 Static Lateral Force Procedure

2.2.5.2.1 Design Base Shear. The total design base shear in a given direction shall be determined from the following formula:

$$V = \frac{Z\,I\,C}{R_w} W \qquad (2\text{-}1)$$

WHERE:

Z = Seismic zone factor given in Table 2.2A.
I = Importance factor given Table 2.2D.
R_w = Numerical coefficient given in Table 2.2G.
W = The total seismic dead load defined in Sec. 2.2.5.1.3.
C = Numerical coefficient determined from the following formula:

$$C = \frac{1.25\ S}{T^{2/3}} \qquad (2\text{-}2)$$

WHERE:

S = Site coefficient for soil characteristics given in table 2.2B.

T	=	Fundamental period of vibration, in seconds, of the structure for the direction under consideration determined in accordance with Sec. 2.2.5.2.2.

The value of C need not exceed 2.75 and this value may be used for any structure without regard to soil type of structure period. Except for those requirements where code prescribed forces are scaled up by 3 (R_w/8) the minimum value of the ratio C/R_w shall be 0.075.

2.2.5.2.2 Structure Period. The value of T shall be determined from one of the following methods:

2.2.5.2.2.1 Method A. For all buildings the value of T may be approximated from the following formula:

$$T = C_t (h_n)^{3/4} \tag{2-3}$$

WHERE:

C_t	=	0.085 for steel moment resisting space frames
C_t	=	0.075 for reinforced-concrete moment resisting space frames and eccentric braced steel frames
C_t	=	0.050 for all other structures
h_n	=	Height, in m, above the base to level n.

Alternatively, the value of C_t for structures with concrete or masonry shear walls may be taken as $0.03048 / \sqrt{A_c}$. The value of A_c shall be determined from the following formula.

$$A_c = \Sigma A_e [\, 0.2 + (D_e/h_n)^2 \,] \tag{2-4}$$

WHERE:

A_c	=	The combined effective area in sq. m., of the shear walls in the first story of the structure
A_e	=	The effective horizontal cross-sectional area in sq.m. of a shear wall in the first story of the structure
D_e	=	The length, in m, of a shear wall element in the first story in the direction parallel to the applied forces.

The value of D_e/h_n for use in Formula (2-4) shall not exceed 0.9.

2.2.5.2.2.2 Method B. The fundamental period T may be calculated using the structural properties and deformational characteristics the resisting elements in a properly substantiated analysis. This requirement may be satisfied by using the following formula:

$$T = 2\pi \sqrt{\left(\sum_{i=1}^{n} w_i \delta_i^2 \right) \div \left(g \sum_{i=1}^{n} f_i \delta_i \right)} \qquad (2\text{-}5)$$

The values of f_i represent any lateral force distributed approximately in accordance with the principles of Formula (2-6), (2-7), and (2-8) or any other rational distribution. The elastic deflections, δ_i, shall be calculated using the applied lateral forces, f_i. The value of C shall be not less than 80 percent of the value obtained by using T from Method A.

2.2.5.3 Combinations of Structural Systems. Where combinations of structural system are incorporated into the same structure, the following requirements shall be satisfied.

2.2.5.3.1 Vertical Combinations. The value of R_w used in the design of any story shall be less than or equal to the value of R_w used in the given direction for the story above.

EXCEPTION: This requirement need not apply to any story where the dead load above that story is less than 10 percent of the total dead weight of the structure.

Structures may be designed using the procedures of Sec. 2.2.5 under the following conditions:

(1) The entire structure is designed using the lowest R_w value of the lateral force resisting systems used.

(2) The following two-stage analysis procedure may be used for structures conforming to Sec. 2.2.4.8.1(3):

(a) The tower portion shall be designed as a separate structure, supported laterally by a platform, using the appropriate value of R_w.

(b) The platform shall be designed as a separate structure using the appropriate value of R_w. The reactions of the tower portion shall be increased by the ratio of the R_w values of the two portions. These factored reactions shall be applied at the top of the platform in addition to the forces determined for the platform itself.

2.2.5.3.2 Combinations Along Different Axes

(1) In Seismic Zones 3 and 4 where a structure has a Bearing Wall System in only one direction, the value of R_w used for design in the orthogonal direction shall not be greater than that used for the Bearing Wall System.

(2) Any combination of Building Frame Systems, Dual Systems, or Moment Resisting Frame Systems may be used to resist design seismic forces in structures less than 50 m in height. Only combinations of Dual Systems and Special Moment Resisting Space Frames can be used to resist design seismic forces in structures exceeding 50 m in height in Seismic Zones 3 and 4.

2.2.5.4 Vertical Distribution of Force. The total force shall be distributed over the height of the structure in conformance with Formulas (2-6), (2-7), and (2-8) in the absence of a more rigorous procedure.

$$V = F_t + \sum_{i=1}^{n} F_i \qquad (2\text{-}6)$$

The concentrated force F_t, at the top, which is in addition to F_n, shall be determined from the formula:

$$F_t = 0.07\ TV \qquad (2\text{-}7)$$

The value of T used for the purpose of calculating F_t may be the period that corresponds with the design base shear as computed using Formulas (2-1) and (2-2). F_t need not exceed 0.25V and may be considered as zero (0) where T is 0.7 seconds or less. The remaining portion of the base shear shall be distributed over the height of the structure including level n, according to the following formula:

$$F_x = \frac{(V - F_t)\ w_x h_x}{\sum_{i=1}^{n} w_i h_i} \qquad (2\text{-}8)$$

At each level designated as x, the force F_x shall be applied over the area of the building in accordance with the mass distribution at that level. Stresses in each structural element shall be calculated as the effect of forces F_x and F_t applied at the appropriate levels above the base.

2.2.5.5 Horizontal Distribution of Shear. Shears shall be distributed as follows:

2.2.5.5.1 The design story shear, V_x, in any story is the sum of the forces F_x and F_t above that story. V_x shall be distributed to the various elements of the vertical lateral force resisting system in proportion to their stiffnesses, considering the stiffness of the diaphragm. See Sec. 2.2.8.2.4 for rigid elements that are intended to be part of the lateral force resisting system.

2.2.5.5.2 To account for the uncertainties in locations of loads the mass at each level shall be assumed to be displaced from the calculated center of mass in each direction a distance equal to five percent of the building dimension at that level perpendicular to the direction of the force under consideration. The effect of this displacement on the story shear distribution shall be considered.

2.2.5.6 Horizontal Torsional Moments

2.2.5.6.1 Provision shall be made for the increased shears resulting from horizontal torsion where diaphragms are not flexible. Diaphragms shall be considered flexible, for purposes of this provision, when the maximum lateral deformation of the diaphragm is more than two times the average story drift of the associated story. This may be determined by comparing the computed midpoint in-plane deflection of the diaphragm under lateral load with the story drift of adjoining vertical resisting elements under equivalent tributary lateral load.

2.2.5.6.2 The torsional design moment at a given story shall be the moment resulting from eccentricities between applied design lateral forces at levels above that story and the vertical resisting elements in that story plus an accidental torsional moment.

2.2.5.6.3 The accidental torsional moment shall be determined assuming the mass is displaced as per Sec. 2.2.5.5.2.

2.2.5.6.4 Where torsional irregularity exists (plan irregularity type A as defined in Table 2.2F) the effects shall be accounted for by increasing the accidental torsion at each level by an amplification factor, A_x, determined from the following formula :

$$A_x = \left(\frac{\delta_{max}}{1.2\ \delta_{avg}} \right)^2 \qquad (2\text{-}9)$$

WHERE:

δ_{max} = The maximum displacement at Level x

δ_{avg} = The average of the displacements at extreme positions of the building at Level x.

A_x need not exceed 3.0.

The more severe loading for each element shall be considered for design.

2.2.5.7 Overturning. Every structure shall be designed to resist the overturning effects caused by earthquake forces specified in Sec. 2.2.5.4, above. At any level, the overturning moments to be resisted shall be determined using those seismic forces (F_t and F_x) which act on levels above the level under consideration. At any level, the incremental changes of the design overturning moment shall be distributed to the various resisting elements in the manner prescribed in Sec. 2.2.5.5 above. Overturning effects on every elements shall be carried down to the foundation. See Sec. 2.2.8.1 for combining gravity and seismic forces.

2.2.5.7.1 Redistribution of overturning effects may be made to other vertical members if framing members of sufficient strength and stiffness to transmit the required loads are provided.

2.2.5.7.2 Where a lateral load-resisting element is discontinuous, such as for vertical irregularity Type D in Table 2.2E or plan irregularity Type D in Table 2.2F, columns supporting such elements shall have the strength to resist the axial force resulting from the following load combinations in addition to all other applicable load combinations :

$$1.0\ DL + 0.8\ LL + 3(R_w/8)E$$

$$0.85\ DL + 3(R_w/8)E$$

(1) The axial forces in such columns need not exceed the capability of other elements of the structure to transfer these loads to the column.

(2) Such columns shall be capable of carrying the above described axial forces without exceeding the axial strength of the column. For

designs using working stress methods this strength may be determined using an allowable stress increase of 1.7.

(3) Such columns shall meet detailing requirements or member limitations of:

(a) Section 5.21 for concrete in Seismic Zones 3 and 4 and Chapter 4 Part 3 for steel in Seismic Zones 2, 3 and 4. (See Chapter 4).

(b) Section 5.21.9.5 for concrete in Seismic Zone 2.

(c) See Sec. 2.2.10.4 for overturning moments to be resisted at the foundation-soil interface.

2.2.5.8 Story Drift Limitation. Story drift is the displacement of one level relative to the level above or below due to the design lateral forces. Calculated drift shall include translational and torsional deflections.

2.2.5.8.1 Calculated story drift shall not exceed $0.04/R_W$ nor 0.005 times the story height for structures having a fundamental period of less than 0.7 seconds. For structures having a fundamental period of 0.7 seconds or greater the calculated story drift shall not exceed $0.03/R_W$ nor 0.004 times the story height. The period used in this determination shall be the same as that used for determining the base shear.

2.2.5.8.2 These drift limits may be exceeded where it is demonstrated that greater drift can be tolerated by both structural elements and nonstructural elements that could affect life safety.

2.2.5.8.3 The design lateral forces used to determine the calculated drift may be derived from a value of C resulting from a period determined from Sec. 2.2.5.2.2.2 method B neglecting the 80 percent limitation of Sec. 2.2.5.2.2.2 and the lower bound limit of 0.075 for C/R_W.

2.2.5.9 P-Delta Effects. The resulting member forces and moments and the story drifts induced by P-delta effects shall be considered in the evaluation of overall structural frame stability. P-delta need not be considered where the story drift does not exceed $0.02/R_W$.

2.2.5.10 Vertical Component of Seismic Forces. The following requirements apply in Seismic Zones 3 and 4 only.

a. Horizontal cantilever components shall be designed for a net upward force of $0.2 W_p$.

b. In addition to all other applicable load combinations, horizontal prestressed components shall be designed using not more than 50 percent of the dead load for the gravity load, alone or in combination with the lateral force effects.

2.2.6 Dynamic Lateral Force Procedure

2.2.6.1 General. Dynamic analyses procedures, where used, shall conform to the criteria established in this section. The analysis shall be based on ground motions defined using the procedures given in Sec. 2.2.6.2 and shall be performed using established principles of mechanics. Structures which are designed in accordance with this section shall comply with all other applicable requirements of these recommendations.

2.2.6.2 Ground Motion. The ground motion representation may be one of the following:

2.2.6.2.1 The normalized response spectra given in Figure 2.2A.

2.2.6.2.2 Site Specific Design Spectra. The site specific response spectra shall be based on the geologic, tectonic, seismologic, and soil characteristics associated with the specific site. The spectra shall be developed for a damping ratio of 0.05 unless a different value is shown to be consistent with the anticipated structural behavior at the intensity of shaking established for the site.

2.2.6.2.3 Ground Motion Time Histories. The ground motion time histories developed for the specific site shall be representative of actual earthquake motions. Response spectra from time histories, either individually or in combination, shall approximate the site-specific design spectra conforming to Sec. 2.2.6.2.2 above.

2.2.6.2.4 Structures on Soil Profile Type S4. The following requirements shall be applied when required by Sec. 2.2.4.8.2(4):

2.2.6.2.4.1 The ground motion representation shall be developed in accordance with Sections 2.2.6.2.2 and 2.2.6.2.3 above and shall equal or exceed the motion having a 10 percent probability of exceedance in 50 years at the site.

2.2.6.2.4.2 The effects of lengthening of the structural period on response amplification due to soil-structure resonance shall be included.

2.2.6.2.4.3 The base shear determined by these procedures may be reduced to a design base shear, V, by dividing by a factor not greater than the appropriate R_w factor for the structure.

2.2.6.2.5 The vertical component of ground motion may be defined by scaling corresponding adjusted horizontal accelarations by a factor of two-thirds. Alternate factors may be used when substantiated by site-specific data.

2.2.6.3 Mathematical Model. A mathematical model of the physical structure shall represent the spatial distribution of the mass and stiffness of the structure to an extent which is adequate for the calculation of the significant features of its dynamic response. A three-dimensional model shall be used for the dynamic analysis of structures with highly irregular plan configurations such as those having a plan irregularity defined in Table 2.2F and having a rigid or semi-rigid diaphragm.

2.2.6.4 Description of Analysis Procedures

2.2.6.4.1 Response Spectrum Analysis. An elastic dynamic analysis of structure utilizing the peak dynamic response of all modes having a significant contribution to total structural response. Peak modal responses are calculated using the ordinates of the appropriate response spectrum curve which correspond to the modal periods. Maximum modal contributions are combined in statistical manner to obtain an approximate total structural response.

2.2.6.4.2 Time History Analysis. An elastic or inelastic dynamic analysis in which a mathematical model of the structure is subjected to a specified ground motion time history. The structure's time-dependent dynamic response to these motion is obtained through numerical integration of its equations of motion.

2.2.6.5 Response Spectrum Analysis

2.2.6.5.1 Number of Modes. The requirement of Sec. 2.2.6.4.1 that all significant modes be included may be satisfied by demonstrating that, for the modes considered, at least 90 percent of the participating mass of the structure is included in the calculation of response for each principal horizontal direction.

2.2.6.5.2 Combining Modes. The peak member forces, displacements, story forces, story shears, and base reactions for each mode shall be combined using established procedures in order to estimate resultant maximum values of these response parameters. When three dimensional models are used for analysis, modal interaction effects shall be considered when combining modal maxima.

2.2.6.5.3 Scaling of Results. Where the base shear for a given direction, determined using these procedures, is different than the base shear by the procedures in Section 2.2.5, the adjustment procedures given below shall be followed. All corresponding response parameters, including member forces and moments, shall be adjusted proportionately. Deflection adjustments shall conform to Sec. 2.2.5.8.3.

2.2.6.5.3.1 When the base shear is less than that determined from Sec. 2.2.5, it shall be increased to the following percentage of the value from Sec. 2.2.5 as follows:

(a) 100 percent for irregular structures.

(b) 90 percent for regular structures except that the base shear shall not be less than 80 percent of that determined using T from Sec. 2.2.5.2.2.1.

2.2.6.5.3.2 When the base shear is greater than that determined from Sec. 2.2.5, the value need not exceed that required by Sec. 2.2.6.5.3.1 above, except for structures required to conform to Sec. 2.2.6.2.4.

2.2.6.5.4 Directional Effects. Directional effects for horizontal ground motion shall conform to the requirements of Sections 2.2.5.1.1 and 2.2.5.1.2. The effects of vertical ground motions on horizontal cantilevers and prestressed elements shall be considered in accordance with Sec. 2.2.5.10. Alternately, vertical seismic response may be determined by dynamic response methods; in no case shall the response used for design be less than that obtained by the static method.

2.2.6.5.5 Torsion. The analysis shall account for torsional effects, including accidental torsional effects as prescribed in Sec. 2.2.5.6. Where three-dimensional models are used for analysis, effects of accidental torsion shall be accounted for by appropriate adjustments in the model such as adjustment of mass locations, or by equivalent static procedures such as provided in Sec. 2.2.5.6.

2.2.6.5.6 Dual Systems. Where the lateral force resisting system consists of a dual system as defined in Sec. 2.2.4.6.4, the system shall satisfy the following requirements:

(1) The combined system shall be capable of resisting the base shear determined in accordance with this section.

(2) The back-up Special Moment-Resisting Space Frame shall be capable of resisting 25 percent of the base shear used for the design of the total system. This 25 percent of the total base shear may be applied to the back-up space frame using either the procedure of Sec. 2.2.5.4 or those of this section.

2.2.6.6 Time History Analysis. Time history analyses shall meet the requirements of Sec. 2.2.4.10.

2.2.7 Lateral Force on Elements of structures and Non-structural Components Supported by Structures

2.2.7.1 Parts and portions of structures, permanent non-structural components and the attachments for them, and the attachments for permanent equipment supported by a structure shall be designed to resist seismic forces prescribed in this section.

2.2.7.1.1 Attachments shall include anchorages and required bracing. Friction shall not be considered to provide resistance to seismic forces.

EXCEPTION: Friction may be utilized to resist shear when the normal forces at the support interface are due to the effects of lateral forces and the effects of gravity forces are neglected.

2.2.7.1.2 Non-rigid equipment which is needed for Occupancy Category I emergency operations or for life safety systems, or whose structural failure would cause a life hazard, shall be designed for seismic forces.

EXCEPTION: Equipment weighing less than 1.8 kN, furniture, or temporary or movable equipment.

2.2.7.2 Each element or component specified in Sec. 2.2.7.1 shall be designed to resist a total lateral seismic force, F_p, given by the following formula:

$$F_p = ZIC_pW_p \qquad (2\text{-}10)$$

WHERE:

W_p = the weight of an element or component

C_p = coefficient given in Table 2.2H

2.2.7.2.1 The values of Z and I shall be the values used for the building.

EXCEPTIONS:

1. For anchorage of machinery and equipment required for life safety systems, the value of I shall be taken as 1.5.

2. For the design of tanks and vessels containing sufficient quantities of highly toxic or explosive substances to be hazardous to the safety of the general public if released, the value of I shall be taken as 1.5.

3. The value of I for panel connectors shall be 1.0 for the entire connection. See Sec. 2.2.8.2.4.2(g).

2.2.7.2.2 The coefficient, C_p, is for elements of structures and non-structural components, and for equipment which is both rigid and rigidly supported. Rigid and rigidly supported equipment is defined as having a fixed base period less than or equal to 0.06 seconds. Non-rigid or flexibly supported equipment is defined as a system having a fixed base period greater than 0.06 seconds.

2.2.7.2.3 The lateral forces calculated for non-rigid items or flexibly supported items, supported by a structure and located above grade, shall be determined considering both the dynamic properties of the element or component and those of the structure which supports it, but the value of C_p shall not be less than that listed in Table 2.2H. In the absence of a detailed analysis, the value of C_p for non-rigid or flexibly supported equipment located above grade on a structure shall be taken as twice the value listed in Table 2.2H, but need not exceed 2.0.

2.2.7.2.4 The value of C_p for elements or components supported at or below ground level may be ⅔ of the value set forth in Table 2.2H. However, the design lateral forces for an element or component which is self-supporting and is mounted at or below grade may be, and shall not be less than would be obtained using the provisions of Sec. 2.2.9.

2.2.7.2.5 The design lateral forces determined using Formula (2-10) shall be distributed in proportion to the mass distribution of the element or component.

2.2.7.2.6 Forces determined using Formula (2-10) shall be used to design elements or components and their connections and anchorage to the structure, and to design members and connections which transfers the forces to the seismic resisting system.

2.2.7.2.7 For applicable forces in connectors for exterior panels and in diaphragms, refer to Sections 2.2.8.2.4 and 2.2.8.2.10, respectively.

2.2.7.2.8 Forces shall be applied in the horizontal directions which result in the most critical loadings for design.

2.2.7.3 Design specifications for equipment shall either specify the design lateral forces prescribed herein or reference these recommendations.

2.2.7.4 For equipment in facilities assigned to Occupancy Categories I and II and for life safety systems, the design and detailing of equipment which needs to be functional following a major earthquake shall consider the effect of drift.

2.2.7.5 Where an approved national standard or approved physical test data provide a basis for the earthquake resistant design of a particular type of equipment or other non-structural component, such a standard or data may be accepted as a basis for design of the items with the following limitations:

a. These recommendations shall provide minimum values for the design of the anchorage and the members and connections which transfer the forces to the seismic resisting system.

b. The force, F_p, and the overturning moment used in the design of the non-structural component shall be not less than 80 percent of the values that would be obtained using these recommendations.

2.2.8 Detailed Systems Design Requirements

2.2.8.1 General. All structural framing systems shall comply with the requirements of Sec. 2.2.4. Only the elements of the designated seismic force resisting system can be used to resist design forces. The individual components shall be designed to resist the prescribed design seismic forces acting on them. The components shall also comply with the specific requirements for the material contained in this Code. In addition, such framing systems and components shall comply with the detailed system design requirements contained in this section.

2.2.8.1.1 Combined Vertical and Horizontal Forces. All building components shall be designed to resist the effects of the seismic forces prescribed herein and the effects of gravity loadings from dead and live loads.

2.2.8.1.2 Uplift Effects. Consideration shall be given to design for uplift effects caused by seismic loads. For materials in which working stress procedure are used for design, dead loads used to reduce uplift shall be multiplied by 0.85.

2.2.8.1.3 Orthogonal Effects

2.2.8.1.3.1 In seismic Zones 2, 3 and 4 provision shall be made for the effects of earthquake motions acting in directions other than parallel to the direction of resistance under consideration in each of the following circumstances:

(a) The structure has plan irregularity Type E as given in Table 2.2F.

(b) The structure has plan irregularity Type A as given in Table 2.2F for both major axes.

(c) A column of a structure forms part of two or more intersecting lateral force resisting systems.

EXCEPTION: If the axial load in the column due to seismic forces acting in either direction is less than 20 percent of the allowable column axial load.

2.2.8.1.3.2 The requirement that orthogonal effects be considered may be satisfied by designing such elements for 100 percent of the prescribed seismic forces in one direction plus 30 percent of the prescribed forces in the perpendicular direction. The combination requiring the greater component strength shall be used for design. Alternatively, the effects of the two orthogonal directions may be combined on a square-root-of-the-sum-of-the squares (SRSS) basis. When the SRSS method of combining directional effects is used, each term computed shall be assigned the sign that will result in the most conservative result.

2.2.8.2 Structural Framing Systems

2.2.8.2.1 General. Four general types of building framing systems defined in Sec. 2.2.4.6 are recognized in these provisions and shown in Table 2-G. Each type is subdivided by the types of vertical elements used to resist lateral seismic forces. Special framing requirements are given in this section.

2.2.8.2.2 Detailing Requirements for Combinations of Systems. For components common to different structural systems, the more restrictive detailing requirements shall be used.

2.2.8.2.3 Connections. Connections which resist prescribed seismic forces shall be designed and detailed on the drawings.

2.2.8.2.4 Deformation Compatibility. All framing elements not required by design to be part of the lateral force resisting system shall be investigated and shown to be adequate for vertical load carrying capacity when displaced $3(R_w/8)$ times the displacements resulting from the required lateral forces. P-delta effects on such elements shall be accounted for. For designs which are based on working stress procedures, this capacity may be determined using an allowable stress increase of 1.7.

2.2.8.2.4.1 Adjoining Rigid Elements. Moment-resisting space frames may be enclosed by or adjoined by more rigid elements which would tend to prevent the space frame from resisting lateral forces where it can be shown that the action or failure of the more rigid elements will not impair the vertical and lateral load resisting ability of the space frame.

2.2.8.2.4.2 Exterior Elements. Exterior non-bearing, non-shear wall-panels or elements which are attached to or enclose the exterior, shall be designed to resist the forces per Formula (2-10) and shall accommodate movements of the structure resulting from lateral forces or temperature changes. Such elements shall be supported by structural members or by mechanical connections and fasteners joining them to structural members in accordance with the following provisions:

(a) Connections and panel joints shall allow for a relative movement between stories of not less than two times story drift caused by wind, $3(R_w/8)$ times the calculated elastic story drift caused by design seismic forces, or 13 mm, whichever is greater.

(b) Connections to permit movement in the plane of the panel for story drift shall be: sliding connections using slotted or oversize holes, connections which permit movement by bending of steel, or other connections providing equivalent sliding and ductility capacity.

(c) Bodies of connections shall have sufficient ductility and rotation capacity to preclude fracture of the anchoring elements or brittle failures at or near welds.

(d) The body of the connection shall be designed for 1⅓ times the force determined by Formula (2-10).

(e) All fasteners in the connection system, such as bolts, inserts, welds, dowels, etc., shall be designed for 4 times the forces determined by Formula (2-10).

(f) Fasteners embedded in concrete shall be attached to, or hooked around, reinforcing steel or otherwise terminated so as to effectively transfer forces to the reinforcing steel.

(g) The value of the coefficient I shall be 1.0 for the entire connection.

2.2.8.2.5 Ties and Continuity

2.2.8.2.5.1 All parts of a structure shall be interconnected. These connections shall be capable of transmitting the prescribed seismic force to the seismic resisting system. As a minimum, any smaller portions of a building shall be tied to the remainder of the building with elements having the strength to transfer at least $Z/3$ times the weight of the smaller portion.

2.2.8.2.5.2 A positive connections for resisting a horizontal force acting parallel to the member shall be provided for each beam, girder, or truss. This force shall be not less than $Z/5$ times the sum of the dead and live load tributary to the member.

2.2.8.2.6 Collector Elements. Collector elements shall be provided which are capable of transferring the seismic forces originating in other portions of the building to the element providing the resistance to those forces.

2.2.8.2.7 Concrete Frames. Concrete space frames required by design to be part of the lateral force resisting system shall conform to the following:

(1) In seismic Zones 3 and 4 they shall be special moment resisting space frames.

(2) In Seismic Zone 2 they shall, as a minimum, be intermediate moment resisting space frames.

2.2.8.2.8 Anchorage of Concrete or Masonry Walls. Concrete or masonry walls shall be anchored to all floors and roofs which provide lateral support for the wall. The anchorage shall provide a positive direct connection between the wall and floor or roof construction capable of resisting the horizontal forces specified in Sec. 2.2.7, or minimum force of 3kN per meter of wall, whichever is greater. Walls shall be designed to resist bending between anchors where the anchor spacing exceeds 1.2 m. In masonry walls of hollow units or cavity walls, anchors shall be embedded in a reinforced grouted structural element of the wall. Requirements for developing anchorage forces in diaphragms are given in Sec. 2.2.8.2.10 below. Diaphragm deformations shall be considered in the design of the supported walls.

2.2.8.2.9 Boundary Members. Specially detailed boundary members shall be considered for shear walls and shear wall elements whenever their design is governed by flexure.

2.2.8.2.10 Diaphragms. The deflection in the plane of the diaphragm shall not exceed the permissible deflection of the attached elements. Permissible deflection shall be that deflection which will permit the attached element to maintain its structural integrity under the individual loading and continue to support the prescribed loads.

2.2.8.2.10.1 Diaphragm Forces. Floor and roof diaphragms shall be designed to resist the forces determined in accordance with the following formula:

$$F_{px} = \left[\frac{F_t + \sum_{i=x}^{n} F_i}{\sum_{i=x}^{n} w_i} \right] W_{px} \qquad (2\text{-}11)$$

(a) The force F_{px} determined from Formula (2-11) need not exceed 0.75 $Z\,I\,W_{px}$, but shall not be less than 0.35 $Z\,I\,W_{px}$.

(b) When the diaphragm is required to transfer lateral forces from the vertical resisting elements above the diaphragm to other vertical resisting elements below the diaphragm due to offset in the placement of the elements or to changes in stiffness in the vertical elements, these forces shall be added to those determined from Formula (2-11).

2.2.8.2.10.2 Diaphragm Ties. Diaphragms supporting concrete or masonry walls shall have continuous ties or struts between diaphragm chords to distribute the anchorage forces specified in Sec. 2.2.8.2.8 above. Added chords may be used to form sub-diaphragms to transmit the anchorage forces to the main cross ties.

2.2.8.2.10.3 Wood Diaphragms Used to Support Concrete or Masonry Walls. Where wood diaphragms are used to laterally support concrete or masonry walls, the anchorage shall conform to Sec. 2.2.8.2.8 above. In Seismic Zones 3 and 4 the following requirements apply:

(a) Anchorage shall not be accomplished by use of toe nail or nails subject to withdrawal ; nor shall wood ledgers or framing be used in cross-grain bending or cross-gain tension.

(b) The continuous ties required by Sec. 2.2.8.2.10.2 above, shall be in addition to the diaphragm sheathing.

2.2.8.2.10.4 For structures in Seismic Zones 3 and 4 having a plan irregularity of Types A, B, C, or D in Table 2.2F, connections of diaphragms to the vertical elements and to collectors, and connections of collectors to the vertical elements shall be designed without considering the one-third increase usually permitted in allowable stresses for elements resisting earthquake forces.

2.2.8.2.10.5 For structures in Seismic Zones 3 and 4 having a plan irregularity of Type B in Table 2.2F, diaphragm chords and collectors shall be designed considering independent movement of the projecting wings of the structure. Each of these diaphragm elements shall be designed for the more severe of the following two assumptions:

(a) Motion of the projecting wings in the same direction.

(b) Motion of the projecting wings in opposing directions.

EXCEPTION: This requirement may be deemed satisfied if the procedures of Section 2.2.6, in conjunction with a three-dimensional model have been used to determine the lateral seismic forces for design.

2.2.8.2.11 Framing Below the Base

2.2.8.2.11.1 General. The strength and stiffness of the framing between the base and the foundation shall not be less than that of the superstructure. The special detailing requirements of this Code, as appropriate, shall apply to columns supporting discontinuous lateral force resisting elements and to SMRSF, IMRSF, and EBF system elements below the base which are required to transmit the forces resulting from lateral loads to the foundation.

2.2.8.2.11.2 Foundations. The foundation shall be capable of transmitting the design base shear and the overturning forces defined in Sec. 2.2.5 from the structure into the supporting soil, but the short-term dynamic nature of the loads may be taken into account in establishing the soil properties. Sec. 2.2.10 defines additional requirements for specific types of foundation construction.

2.2.8.2.12 Building Separations. All structures shall be separated structurally from adjoining structures by a distance sufficient to avoid contact under deflection from a seismic motion. Separations shall allow for $3(R_w/8)$ times the displacement due to design seismic forces.

2.2.9 Non-Building Structures

2.2.9.1 General

2.2.9.1.1 Non-building structures include all self-supporting structures other than buildings which carry gravity loads and resist the effects of earthquake. Any non-building structure whose design basis is or can be under the purview of a building official shall be designed to resist the minimum lateral forces specified in these recommendations. Design shall conform to the applicable provisions of other sections of these recommendations modified by the requirements contained in this section.

2.2.9.1.2 The minimum design lateral forces prescribed in these recommendations are at a service level (rather than yield or ultimate level). The design of non-building structures shall provide sufficient strength and ductility, consistent with the provisions specified herein for buildings, to resist the effects of seismic ground motions as represented by these design forces.

2.2.9.1.2.1 When applicable, allowable stresses and other detailed design criteria shall be obtained from other sections of these recommendations, or its referenced codes and standards.

2.2.9.1.2.2 When applicable design stresses and other design criteria are not contained in or referenced by these recommendations, such criteria shall be obtained from approved national standards.

2.2.9.1.3 The weight W for non-building structures shall include all dead load as defined for buildings in Sec. 2.2.5.1.3. For purposes of calculating design seismic forces in non-building structures, W shall also include all normal operating contents for items such as tanks, vessels, bins and piping.

2.2.9.1.4 The fundamental period of the structure shall be determined by rational methods such as by using Method B in Sec. 2.2.5.2.2.

2.2.9.1.5 The drift limitations of Sec. 2.2.5.8.1 need not apply to non-building structures. Drift limitations shall be established for structural or non-structural elements whose failure would cause life hazards. P-delta effects shall be considered for structures whose calculated drifts exceed the values in Sec. 2.2.5.8.1.

2.2.9.1.6 In Seismic Zones 3 and 4, structures which support flexible non-structural elements whose combined gravity weight exceeds 25 percent of the weight of the structure shall be designed considering interaction effects between the structure and the supported elements.

2.2.9.2 The lateral force procedure for non-building structures with structural systems similar to buildings (those with structural systems listed in Table 2.2G) shall be selected in accordance with the provisions of Sec. 2.2.4.

EXCEPTION: Intermediate Moment Resisting Space Frames (IMRSF) may be used in Zones 3 and 4 for non-building structures in Occupancy Categories III and IV if (1) the structure is less than 15 m. in height, and (2) an R_w = 4.0 is used for design.

2.2.9.3 Rigid structures (those with period T less than 0.06 seconds) including their anchorages, shall be designed for the lateral force obtained from Formula (2-12).

$$V = 0.5\,Z\,I\,W \qquad (2\text{-}12)$$

The force V shall be distributed according to the distribution of mass and shall be assumed to act in any horizontal direction.

2.2.9.4 Flat-bottom tanks or other tanks with supported bottoms, founded at or below grade, shall be designed to resist the seismic forces calculated using the procedures in Sec. 2.2.9.3 above for rigid structures considering the entire weight of the tank and its contents. Alternatively, such tanks may be designed using one of the two procedures described below.

2.2.9.4.1 A response spectrum analysis, which includes consideration of the actual ground motion anticipated at the site and the inertial effects of the contained fluid.

2.2.9.4.2 A design basis prescribed for the particular type of tank by an approved national standard, provided that the seismic zones and occupancy categories shall be in conformance with the requirements of Sec. 2.2.4.2 and Sec. 2.2.4.4, respectively.

2.2.9.5 Non-building structures which are not covered by Sections 2.2.9.2 through 2.2.9.4 above, shall be designed to resist minimum seismic lateral forces not less than those determined in accordance with the provisions in Sec. 2.2.5 with the following additions and exceptions:

a. The factor R_w shall be as given in Table 2.2I. The ratio C/R_w used for design shall be not less than 0.5.

b. The vertical distribution of the lateral seismic forces in structures covered by this section may be determined in one of the two following methods.

(1) Using the provisions of Sec. 2.2.5.4.

(2) Using the procedures of Sec. 2.2.6.

EXCEPTION : For irregular structures assigned to Occupancy Categories I and II, which cannot be modeled as a single mass, the procedures of Sec. 2.2.6 shall be used.

c. Where an approved national standard provides a basis for the earthquake resistant design of a particular type of non-building structure covered by this Sec. 2.2.9.5, such a standard may be used subject to the following limitations.

(1) The seismic zones and occupancy categories shall be in conformance with the requirements of Sections 2.2.4.2 and 2.2.4.4, respectively.

(2) The values for total lateral force and total base overturning moment used in design shall not be less than 80 percent of the values that would be obtained using these recommendations.

2.2.10 Foundations

2.2.10.1 General. The design and construction of foundations, foundation components and the connection of the superstructure elements thereto shall conform to the requirements of this section and other applicable requirements. Where appropriate degradation of soil capacity resulting from liquefaction or similar phenomena during an earthquake shall be taken into account.

2.2.10.2 Soil Capacities. The capacity of the foundation soil in bearing or the capacity of the soil interface between pile, pier or caisson and the soil shall be sufficient to support the structure with all prescribed loads, other than earthquake forces, taking due account of the settlement that the structure is capable of withstanding. For the load combination including earthquake, the soil capacity must be sufficient to resist loads at acceptable strains considering both the short time of loading and the dynamic properties of the soil. Allowable soil stress may be increased by more than 33 percent of the allowable if substantiated by geotechnical data. For piles, this refers to pile capacity as determined by pile soil-friction or bearing.

2.2.10.3 Superstructure-to-Foundation Connection. The connection of superstructure elements to the foundation shall be adequate to transmit to the foundation the forces for which the elements are required to be designed.

2.2.10.4 Foundation-Soil Interface. For regular buildings, the force F_t may be omitted when determining the overturning moment to be resisted at the foundation-soil interface.

2.2.10.5 Special Requirements for Piles and Caissons

2.2.10.5.1 Piles and caissons shall be designed for flexure whenever the tops of such members will be displaced by earthquake motions. The criteria and detailing requirements of Sections 5.21 for concrete and Chapter 4 Part 3 for steel shall apply for a length of such members equal to 120 percent of the flexural length.

2.2.10.5.2 Footing Interconnection

2.2.10.5.2.1 Pile caps shall be completely interconnected by strut ties or approved equivalent means.

2.2.10.5.2.2 All strut ties shall be capable of resisting in tension or compression a force not less than 10 percent of the larger footing or column load unless it can be demonstrated that equivalent restraint can be provided by other approved means.

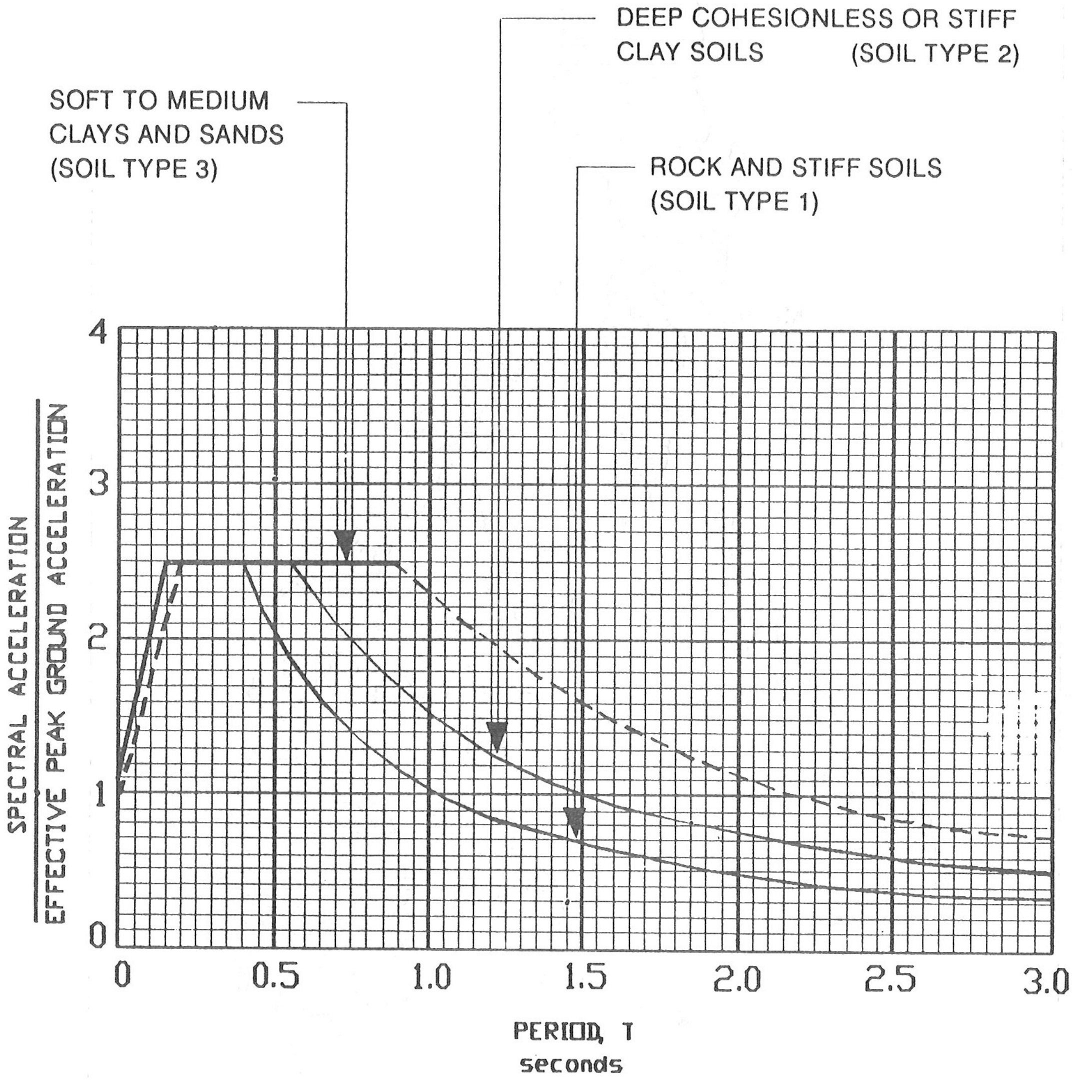


Figure 2.2-A. Normal Response Spectral Shapes

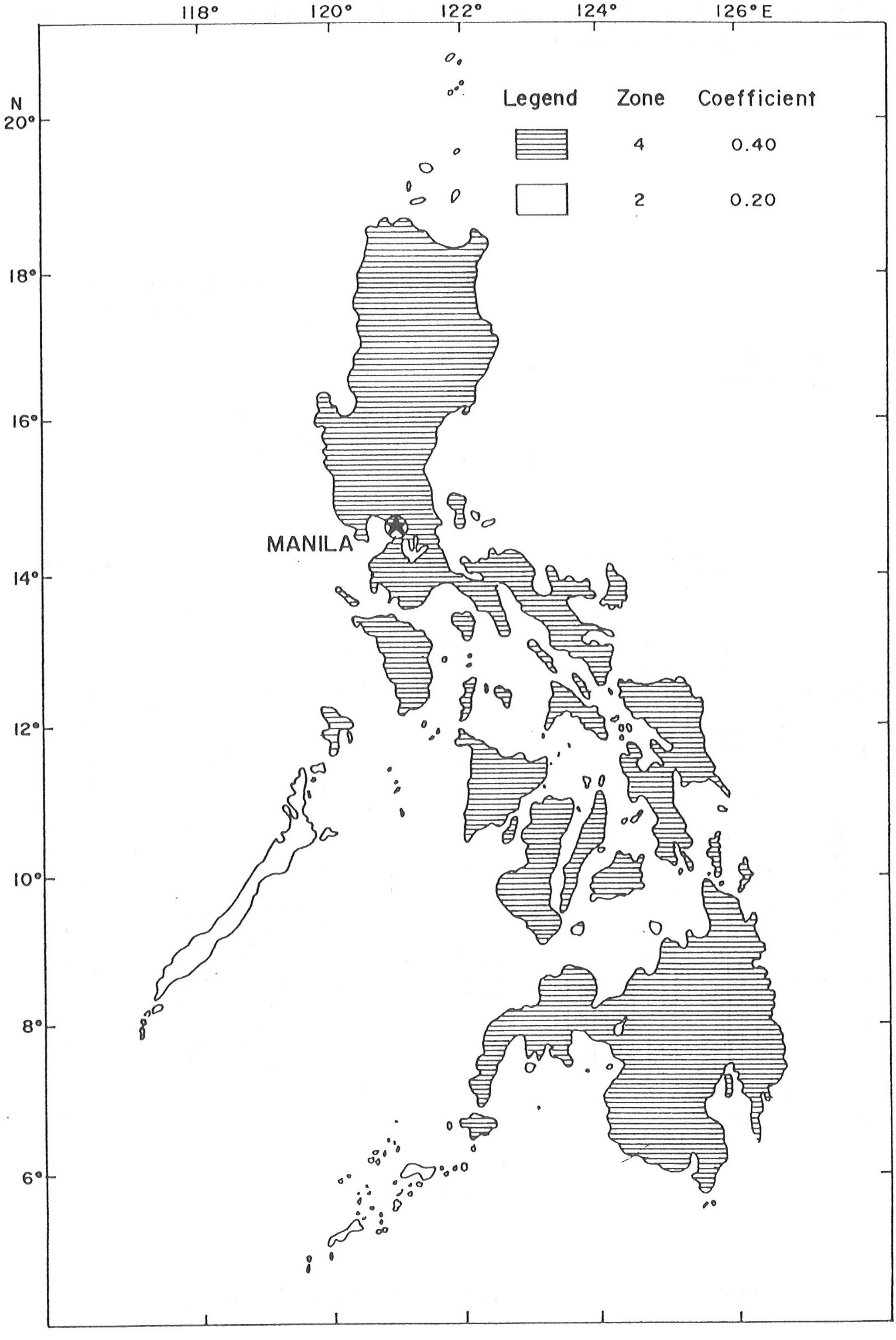


Figure 2.2-B. Seismic Zone Map of the Philippines

TABLE 2.2A
SEISMIC ZONE FACTOR Z

Zone	1	2	3	4
Z	**	0.2	0.3	0.4

** Not used in the Philippines

TABLE 2.2B
SITE COEFFICIENTS [1]

Type	Description	S Factor
S_1	A soil profile with either (a) A rock-like material characterized by a shear-wave velocity greater than 760 m per second or by other suitable means of classification or (b) stiff or dense soil condition where the soil depth is less than 60 m	1.0
S_2	A soil profile with dense or stiff soil conditions, where the soil depth exceeds 60 m or more.	1.2
S_3	A soil profile 12 m or more in depth and containing more than 6 m of soft to medium stiff clay but not more than 12 m of soft clay	1.5
S_4	A soil profile containing more than 12 m of soft clay	2.0

(1) The site factor shall be established from properly substantiated geotechnical data. In locations where the soil properties are not known in sufficient detail to determine the soil profile type, soil profile S_3 shall be used. Soil profile S_4 need not be used unless the Building Official determines that soil profile S_4 may be present at the site or in the event that soil profile S_4 is established by geotechnical data, in which case soil profile S_4 will be used.

TABLE 2.2C
OCCUPANCY CATEGORIES

Occupancy Categories	Occupancy Type of Function of Structures
I Essential Facilities	Hospitals and other medical facilities having surgery, and emergency treatment areas.
	Fire and police stations
	Tanks or other structures containing, housing, or supporting water or other fire-suppression materials or equipment required for the protection of essential or hazardous facilities, or special occupancy structures.
	Emergency vehicle and equipment shelters and garages
	Structures and equipment in emergency preparedness centers
	Stand-by-power generating equipment for essential facilities
	Structures and equipment in communication centers and other facilities required for emergency response.
II Hazardous Facilities	Structures housing, supporting or containing sufficient quantities of toxic or explosive substances to be dangerous to the safety of the general public if released.
III Special Occupancy Structures	Covered structures whose primary occupancy is public assembly–capacity more than 300 persons.
	Buildings for schools (through secondary) or day-care centers–capacity more than 250 students.
	Buildings for colleges or adult education schools–capacity more than 500 students
	Medical facilties with 50 or more resident incapacitated patients, but not included above.
	Jails and detention facilities.
	All structures with occupancy more than 5000 persons.
	Structures and equipment in power generating stations and other public utility facilities not included above, and required for continued operation
IV Standard Occupancy Structure	All structures having occupancies or functions not listed above.

TABLE 2.2D
OCCUPANCY REQUIREMENTS

Occupancy Category (1) (2)	Importance Factor (3) I	
	Earthquake	Wind
I. Essential Facilities	1.25	1.15
II. Hazardous Facilities	1.25	1.15
III. Special Occupancy Structures	1.00	1.00
IV. Standard Occupancy Structures	1.00	1.00

(1) Occupancy types or function of structures within each category are listed in Table 2-C.

(2) Review and inspection requirements are given in Section 2.2.11.

(3) For life safety related equipment see Section 2.2.7.2.1.

TABLE 2.2E
VERTICAL STRUCTURAL IRREGULARITIES

	Irregularity Type and Definition	Reference Section
A.	Stiffness Irregularity – Soft Story A soft story is one in which the lateral stiffness is less than 70 percent of that in the story immediately above or less than 40 percent of the combined stiffness of the three stories above.	2.2.4.8.2(2)
B.	Weight (mass) Irregularity Mass irregularity shall be considered to exist where the effective mass of any story is more than 150 percent of the effective mass of an adjacent story. A roof which is lighter than the floor below need not be considered a mass irregularity.	2.2.4.8.2(2)
C.	Vertical Geometric Irregularity Vertical Geometric Irregularity shall be considered to exist where the horizontal dimension of the lateral force resisting system in any story is more than 130 percent of that in an adjacent story. One – story penthouse need not be considered.	2.2.4.8.2(2)
D.	In-Plane Discontinuity in Vertical Lateral Force Resisting Element An in-plane offset of the lateral load resisting elements greater than the length of those elements.	2.2.5.7.2
E.	Discontinuity in Capacity – Weak Story A weak story is one in which the story strength is less than 80 percent of that in the story above. The story strength is the total strength of all seismic resisting elements sharing the story shear for the direction under consideration.	2.2.4.9.1

TABLE 2.2F
PLAN STRUCTURAL IRREGULARITIES

Irregularity Type and Definition	Reference Section
A. Torsional Irregularity, to be considered when diaphragms are not flexible.	
Torsional irregularity shall be considered to exist when the maximum story drift, computed including accidental torsion, at one end of the structure transverse to an axis is more than 1.2 times the average of the story drifts of the two ends of the structure.	2.2.5.6.4, 2.2.8.1.3, 2.2.8.2.10.4
B. Reentrant Corners	
Plan configurations of a structure and its lateral force resisting system contain reentrant corners, where both projections of the structure beyond a reentrant corner are greater than *fifteen* percent of the plan dimension of the structure in the given direction.	2.2.8.2.10.4, 2.2.8.2.10.5
C. Diaphragm Discontinuity	
Diaphragms with abrupt discontinuities or variations in stiffness, including those having cutout or open areas greater than *fifty* percent of the gross enclosed area of the diaphragm.	2.2.8.2.10.4
D. Out-of-Plane Offsets	
Discontinuities in a lateral force path, such as out-of-plane offsets of the vertical elements.	2.2.5.7.2, 2.2.8.2.10.4
E. Nonparallel Systems	
The vertical lateral load resisting elements are not parallel to nor symmetric about the major orthogonal axes of the lateral force resisting system.	2.2.8.1.3

TABLE 2.2G
STRUCTURAL SYSTEMS

Basic Structural System[1]	Lateral Load Resisting System – Description]	Rw[5]	H[2]
A Bearing Wall System	1. Light Framed Walls With Shear Panels		
	a. Plywood Walls for Structures 3-stories or Less	8	20 m
	b. All Other Light Framed Walls	6	20 m
	2. Shear Walls		
	a. Concrete	6	50 m
	b. Masonry	6	15 m
	3. Light Steel Framed Bearing Walls With Tension-Only Bracing	4	20 m
	4. Braced Frames Where Bracing Carries Gravity Loads		
	a. Steel	6	50 m
	b. Concrete[3]	4	—
	c. Heavy Timber	4	20 m
B. Building Frame System	1. Steel Eccentric Braced Frame (EBF)	10	70 m
	2. Light Framed Walls With Shear Panel		
	a. Plywood Walls for Structures 3-stories or Less	9	20 m
	b. All Other Light Framed Walls	7	20 m
	3. Shear Walls		
	a. Concrete	8	70 m
	b. Masonry	8	15 m
	4. Concentric Braced Frames		
	a. Steel	8	50 m
	b. Concrete[3]	8	—
	c. Heavy Timber	8	20 m
C. Moment Resisting Frame System	1. Special Moment Resisting Space Frames (SMRSF)		
	a. Steel	12	N.L.[4]
	b. Concrete	10	N.L.
	2. Concrete Intermediate Moment Resisting Space Frames (IMRSF)[6]	7	—
	3. Ordinary Moment Resisting Space Frames		
	a. Steel	6	50 m
	b. Concrete[3]	5	—
D. Dual System	1. Shear Walls		
	a. Concrete With SMRSF	12	N.L.
	b. Concrete With Concrete IMRSF	9	50 m
	c. Masonry With SMRSF	8	50 m
	d. Masonry With Concrete IMRSF[3]	7	—
	2. Steel EBF With Steel SMRSF	12	N.L.
	3. Concentric Braced Frames		
	a. Steel With Steel SMRSF	10	N.L.
	b. Concrete With Concrete SMRSF[3]	9	—
	c. Concrete With Concrete IMRSF[3]	6	—
E. Undefined Systems	See Section 2.2.4.9.2	—	—

NOTES :

(1) Bas ic Structural Systems are defined in Section 2.2.4.6.
(2) H = Height Limit applicable to Seismic Zones 3 and 4. See Section 2.2.4.7 for exceptions.
(3) Prohibited in Seismic Zones 3 and 4.
(4) N.L. = No Limit
(5) See Section 2.2.5.3 for combination of Structural System.
(6) Prohibited in Seismic Zones 3 and 4, except as permitted in Section 2.2.9.2.

TABLE 2.2H
HORIZONTAL FORCE FACTOR C_p
Applicable to Rigid Items(6)

Elements of Structures and Non-Structural Components(9)	Value of C_p	Note
I. Part or Portion of Structure		
1. Walls, including the following		
a. Unbraced (cantilevered) parapets	2.0	
b. Others exterior walls above the ground floor	0.75	(1)
c. All interior bearing and nonbearing walls and partitions	0.75	
d. Masonry or concrete fences ovêr 2 m high	0.75	
2. Penthouse (except where framed by an extension of the building frame)	0.75	
3. Connections for prefabricated structural elements other than walls, with force applied at center of gravity.	0.75	
4. Diaphragms	—	(3)
II. Non-Structural Components		
1. Exterior and interior ornamentations and appendages	2.0	
2. Chimney, stacks, trussed towers, and tanks on legs		
a. Supported on or projecting as an unbraced cantilever above the roof more than one-half its total height	2.0	
b. All others, including those supported below the roof with unbraced projection above the roof less than one-half its height, or braced or guyed to the structural frame at or above its center of mass.	0.75	
3. Signs and billboards.	2.0	
4. Mechanical, plumbing and electrical equipment and machinery and associated piping.	0.75	(4)
5. Tanks and vessels (plus contents) including support systems and anchorage.	0.75	
6. Storage racks (includes contents).	0.75	
7. Anchorage for permanent floor-supported cabinets and book stacks more than 1.5 m in height (includes contents).	0.75	
8. Anchorage for suspended ceilings and lights fixtures.	0.75	(2)(5)(8)
9. Access floor systems.	0.75	(2)(7)

NOTES:

(1) See Section 2.2.8.2.4.2.

(2) Applies for Seismic Zones 2, 3, and 4 only.

(3) See Section 2.2.8.2.10.

(4) Equipment and machinery shall include but not be limited to such items as boilers, heat exchangers, chillers, pumps, motors, air-handling units, cooling towers, transformers, switch gear control panels, and life safety equipment. It shall include sprinkler systems, other major piping and the ducting, conduit, cable trays, etc. serving such equipment and machinery.

(5) Ceiling weight shall include all light fixtures and other equipment or partitions which are laterally supported by the ceiling. For purposes of determining the lateral seismic force, a ceiling weight of not less than 0.2 KPA shall be used.

(6) See Section 2.2.7.2.2 for the definition of rigid. See Section 2.2.7.2.3 for nonrigid or flexibly supported items.

(7) W_p for access floor systems shall be the dead load of the access floor system plus 25 percent of the floor live load plus 0.5 KPA partition load allowance.

(8) Ceilings constructed of lath and plaster or gypsum board screw or nail attached to suspended members that support a ceiling in a single plane extending from wall to wall need not be analyzed provided the walls are not over 15 m apart.

(9) See Section 2.2.7.2.4 for items supported at or below grade.

TABLE 2.2I
R_W FACTOR FOR NON-BUILDING STRUCTURES

	Structure Type	R_w
1	Tanks, vessels, or pressurized spheres on braced or unbraced legs.	3
2	Cast-in-place concrete silos and chimneys having walls continuous to the foundation.	5
3	All other distributed mass cantilever structures not covered by 2 above, including stacks, chimneys, silos and skirt-supported vertical vessels.	4
4	Trussed towers (freestanding or guyed), guyed stacks and chimneys.	4
5	Inverted pendulum type structures.	3
6	Cooling towers.	5
7	Bins and hoppers on braced or unbraced legs.	4
8	Storage racks.	5
9	Signs and billboards.	5
10	Amusement structures and monuments.	3
11	All other self-supporting structures not otherwise covered.	4

SEC 2.3 WIND PRESSURE

2.3.1 General

Every building or structure and every portion thereof shall be designed and constructed to resist the wind effects determined in accordance with the requirements of this section. Wind shall be assumed to come from any horizontal direction. No reduction in wind pressure shall be taken for the shielding effect of adjacent structures.

2.3.2 Definitions

Basic Wind Speed is the fastest kilometer wind speed associated with an annual probability of 0.02 measured at a point 10 meters above the ground for an area having exposure category C.

Exposure B has terrain with buildings, forest or surface irregularities 6 meters or more in height covering at least 20 percent of the area extending 1.5 kilometers or more from the site.

Exposure C has terrain which is flat and generally open, extending one-half mile or more from the site in any full quadrant.

Exposure D represents the most severe exposure in areas with basic wind speeds of 130 kPH or greater and has terrain which is flat and unobstructed facing large bodies of water over 1.5 km or more in width relative to any quadrant of the building site. Exposure D extends inland from the shoreline or 10 times the building height, whichever is greater.

Open Structure or Story is partially enclosed structure that has a greater area of exterior wall openings on any one wall than the sum of the areas of the openings on all other walls and has more than 15 percent of the wall area open. All windows and doors or other openings in exterior walls shall be considered as openings unless such openings and their frames are specifically detailed and designed to resist the loads on elements and components in accordance with the provisions of this section.

2.3.3 Symbols and Notations

The following symbols and notations apply to the provisions of this part.

P = Design wind pressure

C_e	=	Combined height, exposure and gust factor coefficient as given in Table 2-J
C_q	=	Pressure coefficient for the structure or portion of structure under consideration as given in Table No. 2-K or from Figs. 2.3.B to 2.3.F
q_s	=	Wind stagnation pressure at a height of 10 meters as set forth in Figure 2.3 A
I	=	Importance factor as set forth in Section 2.2D

The minimum basic wind speed at any site shall not be less than 150 kPH

2.3.4 Basic Wind Speed

The minimum basic wind speed for determining design wind pressure shall be taken from Fig. 2.3A. For thos areas where local records or terrain indicate higher 50-year (mean recurrence interval) fastest kilometer wind speeds, these higher values shall be the minimum basic wind speeds.

2.3.5 Exposure

An exposure shall be assigned at each site for which a building or structure is to be designed.

2.3.6 Calculation of Wind Loads

The design wind loads for buildings and other structures as a whole shall be determined using one of the following procedures:

A. Analytical procedure.

1. Design Wind Pressures

a. Design wind pressures for structures or elements of structures shall be determined for any height in accordance with the following formula:

$$P = C_e C_q q_s I \qquad (2\text{-}13)$$

b. The indicated wind pressures do not include allowances for cross wind or torsional loading, vortex shedding or instability due to galloping or flutter. For structures sensitive to dynamic effects, such as buildings with a height-width ratio greater than 5 or structures sensitive to wind-excited oscillations, the designer should refer to recognized literature pertaining to wind load effects or use the wind tunnel procedure.

2. **Primary Frames and Systems.**

a. **General.** The primary frames or load-resisting system of every structure shall be designed for the pressures calculated using Formula (2-13) and the pressure coefficients, C_q, of either Method 1 or Method 2.

The base overturning moment for the entire structure, or for any one of the individual primary lateral resisting elements, shall not exceed two-thirds of the dead-load-resisting moment. For an entire structure with a height-to-width ratio of 0.5 or less in the wind direction and a maximum height of 20 m, the combination of the effects of uplift and overturning may be reduced by one-third. The weight of earth superimposed over footings may be used to calculate the dead-load-resisting moment.

b. **Method 1 (Normal Force Method).** Method 1 shall be used for the design of gabled rigid frames and may be used for any structure. In the Normal Force Method, the wind pressures shall be assumed to act simultaneously normal to all exterior surfaces. For pressures on roofs and leeward walls, C_e shall be evaluated at the mean roof height.

c. **Method 2 (Projected Area Method).** Method 2 may be used for any structure less than 60 m in height except those using gable rigid frames. This method may be used in stability determinations for any structure less than 60 m high. In the Projected Area Method, horizontal pressures shall be assumed to act upon the full vertical projected area of the structure, and the vertical pressures shall be assumed to act simultaneously upon the full horizontal projected area.

3. **Elements and Components of Structures**

Design wind pressures for each element or component of a structure shall be determined from Formula (2-13) and C_q values from Table 2-K, and shall be applied perpendicular to the surface. For outward acting forces the value of C_e shall be obtained from Table 2-J based on the mean roof height and applied for the entire height of the structure. Each element or component shall be designed for the more severe of the following loadings:

1. The pressures determined using C_q values for elements and components acting over the entire tributary area of the element.

2. The pressures determined using C_q values for local areas at discontinuities such as corners, ridges and eaves. These local pressures shall be applied over a distance from a discontinuity of 3 m or 0.1 times the least width of the structure, whichever is less.

The wind pressures from Section 2.3.6.A.1 and 2.3.6.A.2 need not be combined.

4. Open-Frame Towers

Radio towers and other towers of trussed construction shall be designed and constructed to withstand wind pressures specified in this section, multiplied by the shape factors set forth in Table 2-K

5. Miscellaneous Structures

Greenhouses, lath houses, agricultural buildings or fences 4 m or less in height shall be designed in accordance with this Section. However, three-fourths of q_s, but not less than 500 Pa, may be substituted for q_s in Formula (2-13). Pressures on local areas at discontinuities need not be considered.

6. Occupancy Categories

For the purpose of wind-resistant design, each structure shall be placed in one of the occupancy categories listed in Table No. 2.2C. Table No. 2.2D lists importance factors, I, for each category.

B. Wind Tunnel Procedure

1. Properly conducted wind-tunnel tests may be used for the determination of design wind loads in lieu of the design wind Pressures of Section 2.3.6.A.1. This procedure is recommended for those buildings and structures:

   a. Having unusual geometric shapes, response characteristics, or site locations for which channeling effects or bufetting in the wake of upwind obstructions may warrant special consideration.

b. No reliable documentation pertaining to wind effects is available.

c. More accurate wind-loading information is desired.

2. **Conduct of Wind Tunnel Test**

Test for the documentation of mean and fluctuating forces and pressures and the dynamic response of the structure shall be considered to be properly conducted only of:

a. The natural wind has been modeled to account for the variation of wind speed with height.

b. The natural wind has been modeled for the intensity of the longitudinal component of turbulence.

c. The geometric scale of the structural model is not more than three times the geometric scale of the longitudinal component of turbulence.

d. The response characteristics of the wind-tunnel instrumentation are consistent with the measurements to be made.

e. Due regard is given to the dependence of forces and pressures on the Reynolds number.

f. The structural model is scaled with due regard to length, mass distribution, stiffness, and damping.

TABLE 2 – J – COMBINED HEIGHT, EXPOSURE AND GUST FACTOR COEFFICIENT (C_e) [1]

Height Above Average Level Of Adjoining Ground In Meters	Exposure D	Exposure C	Exposure B
0 – 5	1.41	1.08	0.63
6	1.45	1.13	0.67
7	1.48	1.17	0.70
8	1.51	1.20	0.73
9	1.54	1.23	0.76
10	1.56	1.25	0.78
15	1.65	1.35	0.89
20	1.75	1.46	0.98
30	1.87	1.60	1.12
40	1.96	1.70	1.23
60	2.09	1.86	1.41
80	2.17	2.00	1.55
100	2.26	2.09	1.68

[1] Values for intermediate heights above 5 meters may be interpolated.

TABLE 2 - K - PRESSURE COEFFICIENTS (C_q)

STRUCTURE OR PART THEREOF	DESCRIPTION	C_q FACTOR
1. Primary frames and systems	**Method 1** (Normal Force Method)	
	Walls:	
	Windward wall	0.8 inward
	Leeward wall	0.5 outward
	Roofs [1]:	
	Wind perpendicular to ridge	
	Leeward roof or flat roof	0.7 outward
	Windward roof	
	less than 2:12	0.7 outward
	Slope 2:12 to less than 9:12	0.9 outward or 0.3 inward
	Slope 9:12 to 12:12	0.4 inward
	Slope > 12:12	0.7 inward
	Wind parallel to ridge and flat roofs	0.7 outward
	Method 2 (Projected area method)	
	On vertical projected area	
	Structures 12 m or less in height	1.3 horizontal any direction
	Structures over 12 m in height	1.4 horizontal any direction
	On horizontal projected area[1]	0.7 upward
2. Elements and components not in areas of discontinuity [2,4,5]	Wall elements	
	All structures	1.2 inward
	Enclosed structures and Unenclosed structrures	1.2 outward
	Open structures	1.6 outward
	Parapets walls	1.3 inward or outward
	Roof Elements[3]	
	Enclosed structures and Unenclosed structures	
	Slope < 7:12	1.3 outward
	Slope 7:12 to 12:12	1.3 outward or inward
	Open structures	
	Slope < 2:12	1.7 outward
	Slope 2:12 to 7:12	1.6 outward or
	Slope > 7:12 to 12:12	3.0 upward
3. Elements and components in areas of discontinuities [2,4,6]	Wall corners [7]	1.5 outward or 1.2 inward
	Roof eaves, rakes or ridges without overhangs[7]	
	Slope < 2:12	2.3 upward
	Slope 2:12 to 7:12	2.6 outward
	Slope > 7:12 to 12:12	1.6 outward
	For slopes less than 2:12	
	Overhangs at roofeaves, rakes or ridges, and canopies	0.5 added to values above

TABLE 2 – K (continued)

STRUCTURE OR PART THEREOF	DESCRIPTION	C_q FACTOR
4. Chimneys, tanks and solid towers	Square or rectangular Hexagonal or octagonal Round or elliptical	1.4 any direction 1.1 any direction 0.8 any direction
5. Open-frame towers [4, 5]	Square and rectangular Diagonal Normal Triangular	 4.0 3.6 3.2
6. Tower Accessories (such as ladders, conduit, lights and elevators)	Cylindrical members 50 mm or less in diameter Over 50 mm in diameter Flat or angular members	 1.0 0.8 1.3
7. Signs, flagpoles, lightpoles, minor structures [4]		1.4 any direction

[1] For one story or the top story of multistory open structures an additional outward C_q factor of 0.5 shall be used. The most critical combination shall be used for design. For definition of open structure see Section 2.3.2.

[2] Cq values listed are for 1 - square meter tributary areas. For Tributary areas of 10 square meters the value of 0.3 may be subtracted from Cq, except for areas at discontinuities with slopes less than 7:12 where the value of 0.8 may be subracted for Cq. Interpolating may be used for tributary areas between 1 and 10 square meters. For tributary areas greater than 100 square meters use primary frame values.

[3] For slopes greater than 12:12, use wall element values.

[4] Local pressures shall apply over a distance from the discontinuity of 3 m or 0.1 times the least width of the structure, whichever is smaller.

[5] Wind pressures shall be applied to the total normal projected area of all the elements of one face. The forces shall be assumed to act parallel to wind direction.

[6] Discontinuities at wall corners or roof ridges are defined as discontinuous breaks in the surface where the included interior angle measure 170 degrees or less.

[7] Load is to be applied on either side of discontinuity but not simultaneously on both sides.

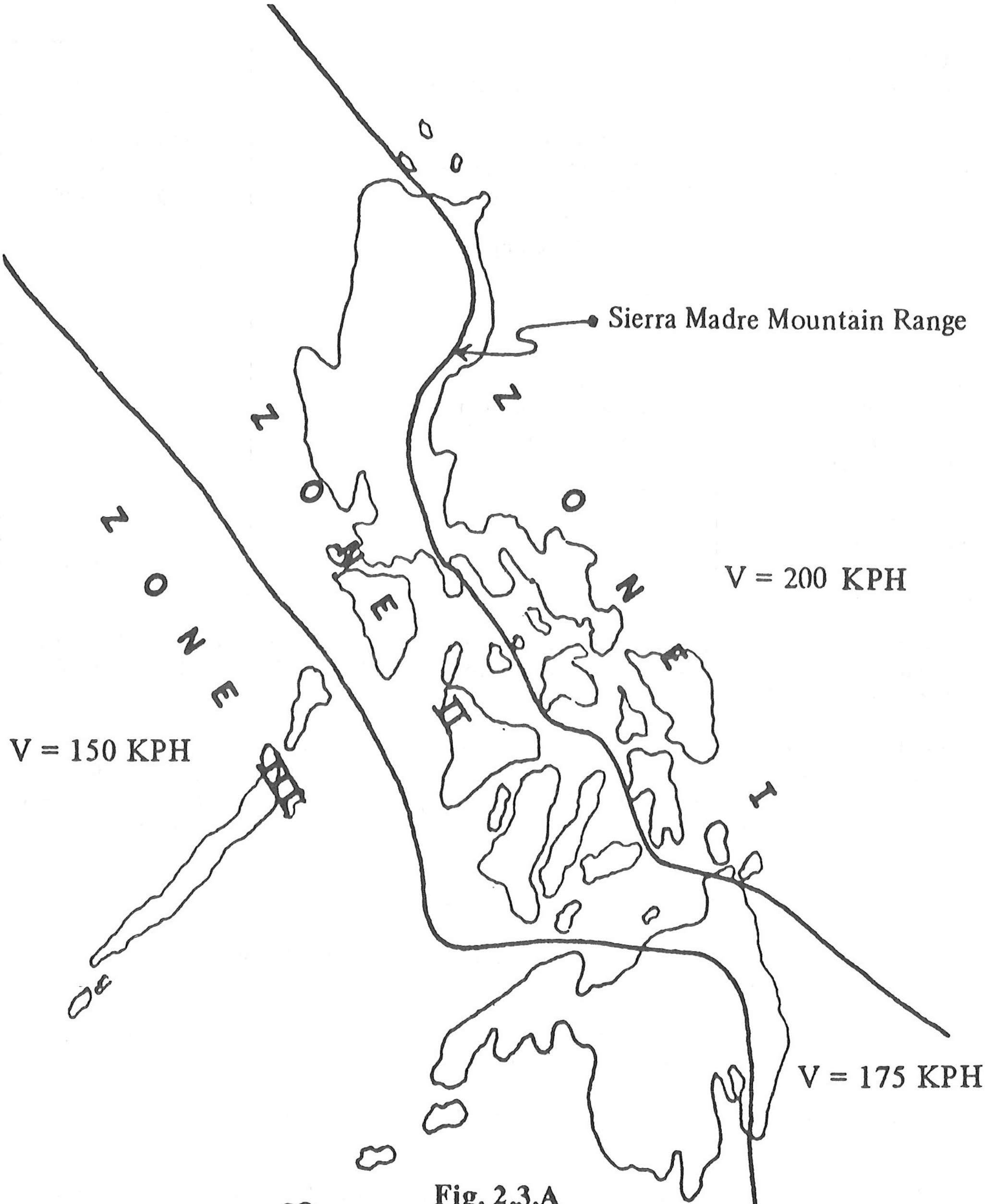


Fig. 2.3.A

WIND SPEEDS IN KPH

Zone	I	II	III
Basic Wind Speed	200	175	150
q_s, wind stagnation pressure	2000 Pa	1500 Pa	1000 Pa

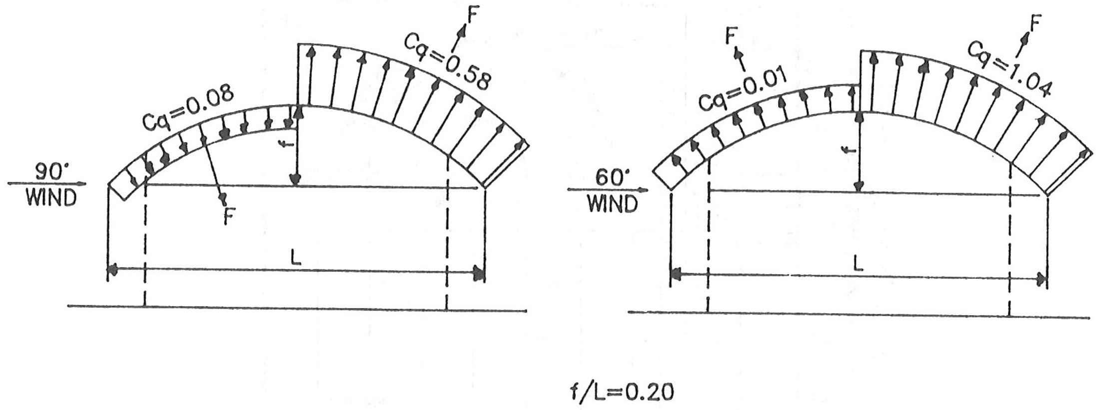


Fig. 2.3B Force Coefficients, Cq for Arched Roofs on Open Sheds

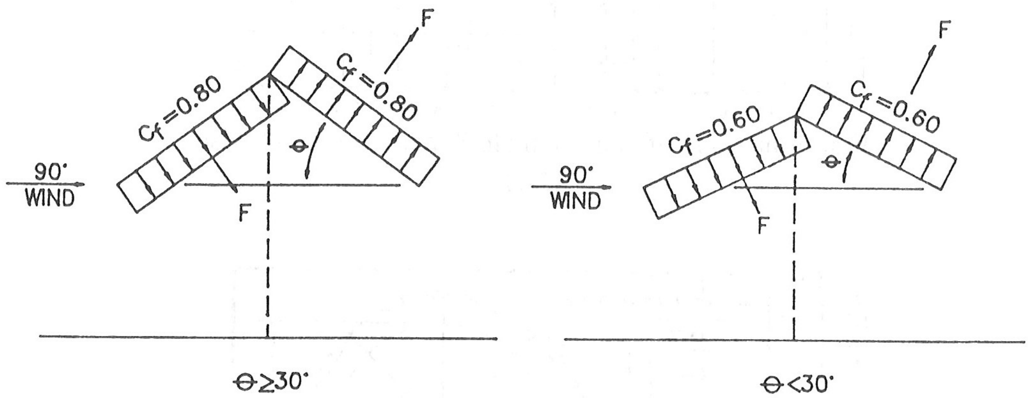


Fig. 2.3C Force Coefficients, Cq for Gable Roofs on Open Sheds

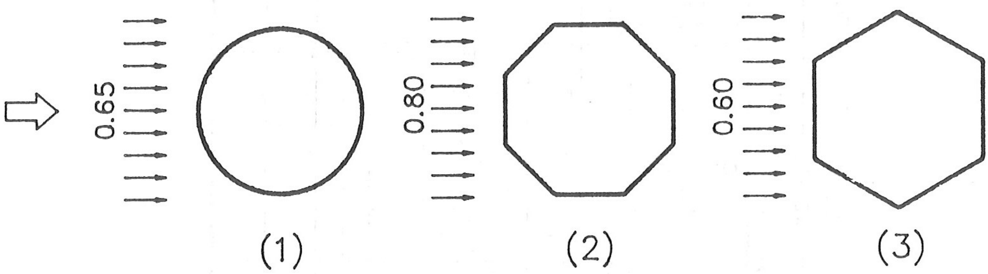
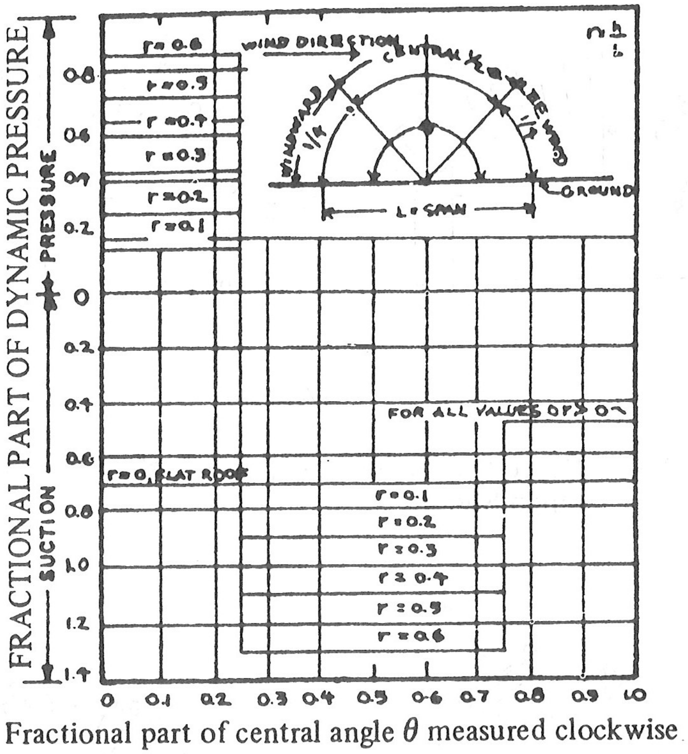


Fig. 2.3D Force Coefficients, Cq for Polygonal Structures


FRACTIONAL PART OF DYNAMIC PRESSURE
PRESSURE
SUCTION
WIND DIRECTION
CENTRAL ½θ
WINDWARD
LEEWARD
GROUND
L = SPAN
r = h/L
r = 0.6
r = 0.5
r = 0.4
r = 0.3
r = 0.2
r = 0.1
r = 0, FLAT ROOF
FOR ALL VALUES OF r > 0
0.8
0.6
0.4
0.2
0
1.0
1.2
1.4
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Fractional part of central angle θ measured clockwise

(28)

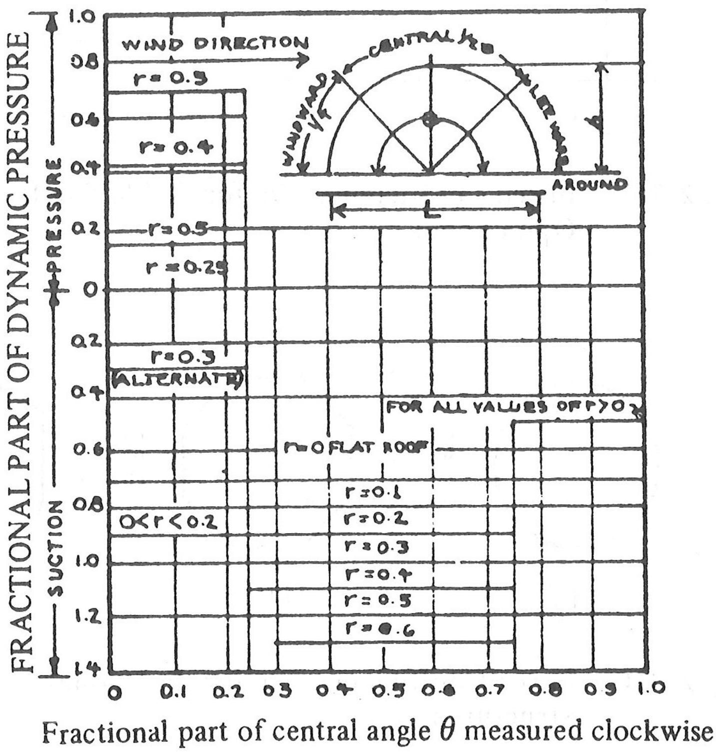
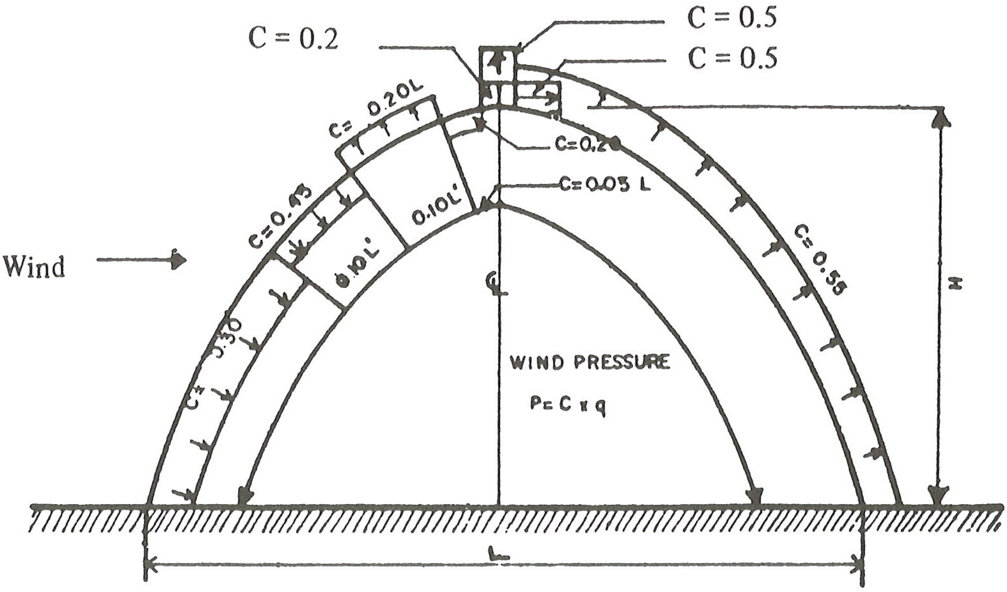

FRACTIONAL PART OF DYNAMIC PRESSURE
PRESSURE
SUCTION
WIND DIRECTION
CENTRAL ½θ
WINDWARD
LEEWARD
GROUND
L
h
r = 0.5
r = 0.4
r = 0.25
r = 0.3 (ALTERNATE)
FOR ALL VALUES OF r > 0
r = 0 FLAT ROOF
0 < r < 0.2
r = 0.1
r = 0.2
r = 0.3
r = 0.4
r = 0.5
r = 0.6
1.0
0.8
0.6
0.4
0.2
0
1.2
1.4
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Fractional part of central angle θ measured clockwise

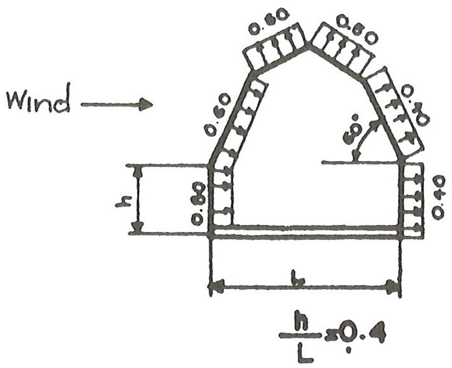
Fig. 2.3.E



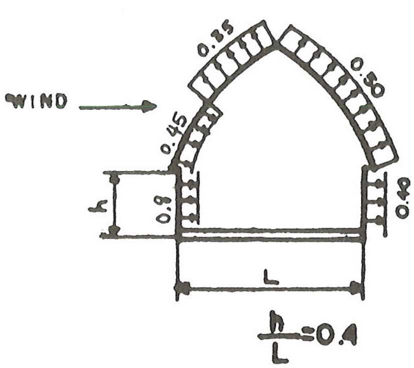
L′ = LENGTH OF ARCH RIB
WIND LOAD DISTRIBUTION WHICH MAY BE USED FOR PARABOLIC ARCH RIBS OF $\frac{M}{L}$ APPROXIMATELY 0.55

(30)

MULTIPLE GABLE ROOF BUILDING



GAMBREL ROOF
(31)



GOTHIC ROOF
(32)

Fig. 2.3.F