CHAPTER 7 - EARTHQUAKE LOADING

7.1 GENERAL

The proper application of these lateral force requirements, both in design and construction, are intended to provide minimum standards toward making buildings and other structures earthquake resistive. The provisions of this Chapter apply to the structure as a unit and also to all parts thereof, including the the structural frame or walls, floors and roof systems, and other elements.

Every structure shall be designed and constructed to resist actions produced by lateral forces as provided in this Chapter. Actions shall be calculated as the effect of a force applied horizontally at each floor or roof level above the base. The force shall be assumed to come from any horizontal direction.

Where prescribed wind loads produce more critical effects, such loads shall be used in lieu of the loads resulting from earthquake forces.

7.2 DEFINITIONS

The following definitions apply to the provisions of this Chapter:

Appendage. An architectural component such as a canopy, marquee, ornamental balcony, or statuary.

Base. The level at which the earthquake motions are considered to be imparted to the structure.

Braced Frame. A vertical truss, or its equivalent, which is provided to resist lateral forces in the frame system and in which the members are subjected primarily to axial stresses.

Component. A part of an architectural, electrical, mechanical or structural system.

Diaphragm. A horizontal or nearly horizontal system designed to transmit seismic forces to the vertical elements of the seismic resisting system.

Ductile Moment-Resisting Space Frame. A moment-resisting space frame complying with the requirements for a ductile moment resisting space frame as given in Appendix B of ESCP 2.

Lateral Force-Resisting System. That part of the structural system assigned to resist the lateral forces prescribed in Section 7.3.

Moment-Resisting Space Frame. A vertical load-carrying space frame in which the members and joints are capable of resisting forces primarily by flexure.

Seismic Forces. The assumed forces prescribed herein, related to the response of the building to earthquake motions, to be used in the design of the building and its components.

Shear Wall. A wall designed to resist lateral forces parallel to the wall.

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

Vertical Load-Carrying Space Frame. A space frame designed to carry all vertical loads.

7.3 MINIMUM EARTHQUAKE FORCES FOR STRUCTURES

Except as provided in Sections 7.6 and 7.8, every structure shall be designed and constructed to resist minimum total lateral seismic forces assumed to act nonconcurrently in the direction of each of the main axes of the structures in accordance with Eq. 7-1

$$F_{tot} = C_s G_{eq} \tag{7-1}$$

where,

C_s is the seismic base shear coefficient and is determined from

$$C_s = \alpha\beta\gamma \tag{7-2}$$

and G_{eq} is the equivalent permanent load and is determined from

$$G_{eq} = G_k + \psi Q_k \tag{7-3}$$

where,

G_k = the characteristic dead load

Q_k = the characteristic live load

ψ = live load incidence factor as given in Table 7-1

Table 7-1 Live Load Incidence Factor, ψ

Type of Structure	ψ
Private dwellings, hotels, offices, hospitals, public buildings, dormitories	0.25
Storage and warehouses	0.50
Silos and tanks for liquids	1.00

In Eq. 7.2, the values of α, β and γ are determined as indicated hereafter.

The coefficient α is the design bedrock acceleration ratio given by

$$\alpha = \alpha_o I \tag{7.4}$$

where,

α_o = the bedrock acceleration ratio for the site and depends on the seismic zone (see Fig. 7.1) as given in Table 7-2

I = the importance factor which depends on the classification of the structure with respect to the economic value and post-disaster use as given in Table 7-3.

Table 7-2 Bedrock Acceleration Ratio, α_o

Zone	3	2	1	0
α_o	0.10	0.05	0.025	0

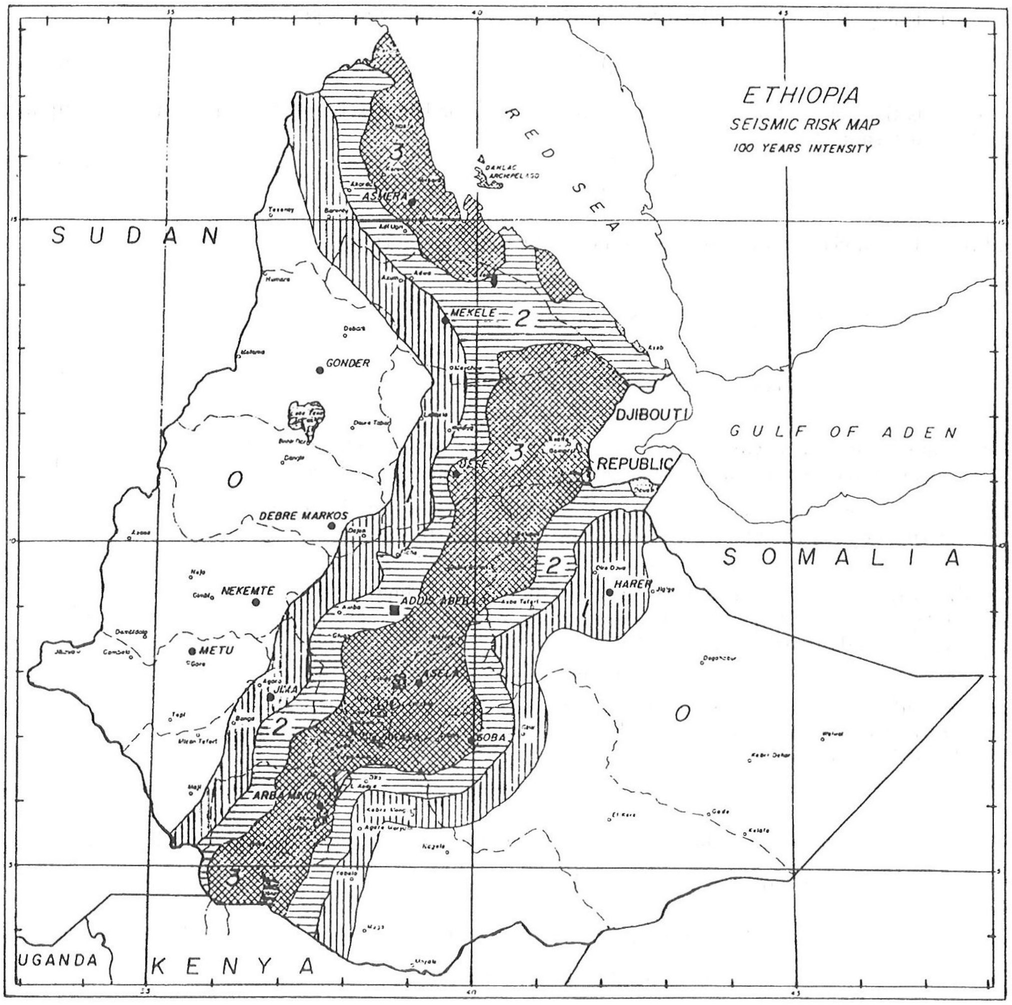

Fig. 7.1 Seismic Zones of Ethiopia

Table 7-3 Structure Importance Factor, *I*

Structure Type	*I*
Structures and buildings to be used during or immediately after an earthquake, such as hospitals, fire stations, broadcasting buildings, power stations, post offices	1.5
Buildings and structures of occupancy	1.0
Single-storey factory buildings not containing highly valuable equipment, small workshop buildings and the like	0.5
Buildings and structures which, if they were to fail, would not involve loss of life or destruction of valuable equipment. Farm buildings and structures not occupied for any length of time. Temporary structures.	0

The cofficient β is the elastic design response factor for the site and is given by

$$\beta = \beta_o S \leqq 2.5 \qquad (7\text{-}5)$$

where β_o is the elastic design response spectrum factor for bedrock foundation and standard damping of 5% as determined from

$$\beta_o = \frac{1.2}{T^{1/2}} \qquad (7\text{-}6)$$

and S is the soil classification and site condition factor given in Table 7-4.

Table 7-4 Soil Classification and Site Condition Factor, S

Classification of Site Condition	S
Rock of any characterstic, either shale-like or crystalline in nature. Such material may be characterized by shear wave velocity greater than 800 meters per second Stiff soil conditions where the soil depth is less than 75 meters and the soil types overlying rock are stable deposits of sands, gravels, or stiff clays.	1.0
A profile with deep cohesionless or stiff clay conditions, including sites where the soil depth exceeds 75 meters and the soil types overlying rock are stable deposits of sands, gravels, or stiff clays.	1.25
A profile with soft- to medium-stiff clays and sands characterized by 10 meters or more of soft- to medium-stiff clays with or without intervening layers of sand or other cohesionless soils.	1.5

The period, T, shall be established using the structural properties and deformational characteristics of resisting elements in a properly substantiated analysis.

In the absence of a period determination as indicated above the value of fundamental elastic period of vibration in seconds, T, for buildings may be determined by Eq. 7-7.

$$T = \frac{0.09h_n}{d^{1/2}} \qquad (7\text{-}7)$$

where,

h_n = height in meters above the base to level n.

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

d = the dimension of the structure in meters, in a direction parallel to the applied forces.

Or in buildings in which the lateral force resisting system consists of moment resisting space frames capable of resisting 100 percent of the required lateral forces and such system is not enclosed by or adjoined by more rigid elements tending to prevent the frame from resisting all the lateral forces, T may be determined by Eq. 7-8

$$T = 0.10n \qquad (7\text{-}8)$$

The coefficient γ is the ductility and energy absorption factor and accounts for response modification due to inelastic behaviour and/or energy-absorptive capacity of the structure and due to damping other than 5%.

The values of γ are given as function of the type of structural system defined in Table 7-5.

The values of γ for structural Types 1 and 2 in Table 7-5 are set on the assumption of compliance with sophisticated design, detailing and construction control requirements in accordance with the state of the art in earthquake engineering and are therefore not recommended for general application.

Table 7-5 Structural System Type Factor, γ

Type	Type or Arrangement of Resisting Elements	Value of γ
1	Building with a ductile moment-resisting space frame with the capacity to resist the total required force. Buildings with a dual structural system consisting of a complete ductile moment-resisting space frame and ductile flexural walls designed in accordance with the following criteria: The frames and ductile flexural walls shall resist the total lateral force in accordance with their relative rigidities considering the interaction of the flexural walls and frames. In this analysis the minimum shear in the frame must be at least 25 percent of the total base shear. Buildings with a dual system consisting of a complete ductile moment-resisting space frame and shear walls or steel bracing designed in accordance with the following criteria: The shear walls or steel bracing acting independently of the ductile moment-resisting space frame shall resist the total required lateral force. The ductile moment-resisting space frame shall have the capacity to resist not less than 25 percent of the required lateral force, but in no case shall the ductile moment-resisting space frame have a lower capacity than that required in accordance with the relative rigidities.	0.3
2	Buildings with ductile flexural walls and buildings with ductile framing systems not otherwise classified in this Table 1 or 3.	0.4
3	Buildings with a dual structural system consisting of a complete ductile moment-resisting space frame with masonry infilling designed in accordance with the following criteria: The wall system comprising the infilling and the confining elements acting independently of the ductile moment-resisting space frames shall resist the total lateral force. The ductile moment-resisting space frame shall have the capacity to resist not less than 25 percent of the required lateral force.	0.5
4	Buildings (other than Types 1, 2 and 3) or reinforced concrete, steel, or reinforced masonry shear walls.	0.5
5	Buildings of unreinforced masonry and all other structural systems except Types 1 to 4 inclusive and those set forth in Table 7-6.	0.8
6	Elevated tanks plus contents on 4 or more crossbraced legs and not supported by a building.	1.0

7.4 DISTRIBUTION OF LATERAL FORCES

7.4.1 Regular Structures or Framing Systems

The total lateral seismic force, F_{tot}, shall be distributed over the height of the structure in accordance with Eqs. 7-9 and 7-10.

A portion F_{no} of the total lateral load shall be assumed to be concentrated at level n according to Eq. 7-9.

$$F_{no} = 0.07TF_{tot} \tag{7-9}$$

F_{no} need not exceed $0.25F_{tot}$ and may be considered as zero where T is 0.7 seconds or less. The remaining portion of the total base shear F_{tot} shall be distributed over the height of the structure including level n according to Eq. 7-10.

$$F_x = \frac{(F_{tot} - F_{no})\ G_x h_x}{\sum_{i=1}^{n} G_i h_i} \tag{7-10}$$

where

G_x, G_i = the portion of G_{eq} located at or assigned to level x or i

h_x, h_i = the height above the base to level x or i

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 on that level.

7.4.2 Setbacks

Buildings having setbacks wherein the plan dimension of the tower in each direction is at least 75 percent of the corresponding plan dimension of the lower part may be considered as uniform buildings without setbacks, providing other irregularities as defined in this Chapter do not exist.

7.4.3 Irregular Structures or Framing System

The distribution of lateral forces in structures which have highly irregular shapes, large differences in lateral resistance or stiffness between adjacent stories or other unusual structural features shall be determined according to specialist literature considering the dynamic characteristics of the structure.

7.4.4 Distribution of Horizontal Shear

Total shear in any horizontal plane shall be distributed to the various elements of the lateral force resisting system in proportion to their rigidities, considering the rigidity of the horizontal bracing system or diaphragm.

Rigid elements that are assumed not to be part of the lateral force resisting system may be incorporated into the buildings provided that their effect on the action of the system is considered and provided for in design.

7.4.5 Horizontal Torsional Moments

Provision shall be made for the increase in shear resulting from the horizontal torsion due to an eccentricity between the center of mass and the center of rigidity. The design eccentricity, e_x, in the horizontal plane of the building shall be computed in each storey in accordance with Eq. 7-11 (a) or (b), whichever is more critical.

$$e_x = 1.5e + 0.05b \qquad (7\text{-}11a)$$

or

$$e_x = e - 0.05b \qquad (7\text{-}11b)$$

where

e = distance between the location of the resultant of all forces at and above the level being considered and the center of rigidity at the level being considered

b = plan dimension of the building in the direction of the computed eccentricity

7.5 OVERTURNING

Every structure shall be designed to resist the overturning effects at its base caused by the earthquake forces specified in Section 7.4.

7.6 LATERAL FORCE ON ELEMENTS OF STRUCTURES

Architectural systems and components and their attachments shall be designed for seismic forces determined from Eq. 7-12, and distributed according to the distribution of mass of the element under consideration.

$$F_c = \alpha\beta_c G_c \qquad (7\text{-}12)$$

where

F_c = the seismic force applied to a component of a building or equipment at its center of gravity

α = the design bedrock acceleration ratio given by Eq. 7-4

β_c = the seismic coefficient for components of architectural system as given in Table 7-6

G_c = the weight of a component of a building or equipment

Table 7-6 Response Coefficient β_c for Parts of Buildings

Category	Part or Portion of Building	Direction of Force	Value of β_c
1	All exterior and interior walls except those of Category 2 and 3	Normal to flat surface	2
2	Cantilever parapet and other cantilever walls except retaining walls	Normal to flat surface	10
3	Horizontally cantilevered floors and beams	Vertically downward or upward	4
4	Exterior and interior ornamentations and appendages	Any direction	10
5	Towers, tanks plus contents, storage racks plus contents, chimneys, smokestacks and penthouses all when connected to or forming part of a building	Any direction	2*
6	Rigid and rigidly mounted equipment and machinery not required for continued operation of essential occupancies, when connected to or a part of a building	Any horizontal direction	2
7	Tank plus effective mass of its contents, when resting on the ground	Any direction	1.5
8	Connections for exterior and interior walls, except those forming part of the main structural system	Any direction	20
9	Floors and roofs acting as diaphragms	In the plane of the diaphragms	1.5**

* When $h/d > 5$ for any building increase value by 50 percent.

** Floors and roofs acting as diaphragms shall be designed for a minimum force corresponding to a value $\beta_c = 1.5$ applied to loads tributary from that storey, unless a greater force results from the distribution of lateral forces in accordance with Section 7.4.

7.7 DRIFT PROVISIONS AND BUILDING SEPARATIONS

Lateral deflections or drift of a storey relative to its adjacent stories shall not exceed 0.005 times the storey height unless it can be demonstrated that greater drift can be tolerated.

All portions of structures shall be designed and constructed to act as an integral unit in resisting horizontal forces unless separated structurally by a distance sufficient to avoid contact under deflection from seismic action.

The displacement obtained by an elastic analysis using the loads given in Section 7.4 shall be multiplied by 3 to give realistic value of anticipated deflections or drifts.

To prevent collision of buildings in an earthquake, adjacent structures shall either be separated by twice the sum of their individual deflections obtained from an elastic analysis using loads given in Section 7.4, or shall be connected to each other.

7.8 ALTERNATE DETERMINATION AND DISTRIBUTION OF SEISMIC FORCES

Nothing in this Code shall be deemed to prohibit the submission of properly substantiated technical data for establishing the lateral forces and distribution by dynamic analysis. In such analysis the dynamic characteristics of the structure shall be considered.

7.9 SPECIAL REQUIREMENTS

7.9.1 Nonstructural Components

Nonstructural components shall be designed so as not to transfer to the structural system any force unaccounted for in the design, and any interaction of rigid elements such as walls and the structural system shall be designed so that the capacity of the structural system is not impaired by the action or failure of the rigid elements.

When required by Section 7.6, all portions or components of the building shall be anchored for the seismic force, F_c, prescribed therein.

7.9.2 Ties and Continuity

All parts of the building shall be interconnected and the connections shall be capable of transmitting the the seismic force, F_c, induced by the parts being connected. As a minimum, any smaller portion of the building shall be tied to the remainder of the building with elements having at least a strength to resist α_o times of the weight of the smaller portion.

A positive connection for resisting a horizontal force shall be provided for each beam, girder or truss to its support which shall have a minimum strength acting along the span of the member equal to 5 percent of the dead and live load reaction.

7.9.3 Foundation Ties

Pile caps and caissons of every building or structure shall be interconnected by ties in at least 2 directions, designed to carry by tension or compression a horizontal force equal to α_o times the smaller pile cap loading, unless it can be demonstrated that equivalent restraint can be provided by other approved methods.

Editorial Notes According to the information provided by the National Delegate, work for a full revision of the code is currently on-going.