REP-94
Structural Design Regulations
for
the Republic of Panama 1994

Chapter 4
Seismic Loads

4.1 General Provisions

4.1.1 **Purpose:** Chapter 4 presents the design and construction criteria of buildings or similar structures, which are subjected to earthquake ground motions. The specified seismic forces are based on the post-elastic energy dissipation in the building. For this reason, the design, detail and construction provisions for the load combinations of structures and members which have the seismic effects shall satisfy and require a greater demand than the combinations which do not have any seismic effects.

4.1.2 **Scope:** All the buildings and their parts shall be designed and constructed to resist the seismic forces caused by the earthquake ground motions prescribed in these provisions. Also the additions to the existent building shall be designed and constructed to resist the seismic forces caused by the earthquake ground motions prescribed in these provisions. The existent buildings and additions to the existent buildings should be only satisfying the provisions in Section 4.1.3.1 through 4.1.3.3 if being requested.

4.1.3 **Application of Provisions**

4.1.4 **Seismic Performance:** The seismic performance is a measure of the protection grade, which is offered to the public and occupants of the building against the potential risks, which is the result of earthquake ground motion effects to the buildings. The seismicity grade and the Group of Exposure to the Seismic Risk (or **Seismic Risk Exposure Group**) are used to classify the buildings into Categories of Seismic Performance. The Group III of Exposure to the Seismic Risk requires the highest protection level, and the **Seismic Performance Category,** E provides the highest performance level of the building required against the earthquake.

4.1.4.1 **Acceleration Maps of Soil due to Earthquake:** The effective peak acceleration relative to velocity (A_v) shall be determined from the map of **Coefficient of Relative Maximum Acceleration to the Velocity (A_v) for the Republic of Panama, REP-94, January of 1994**, or the subsequent latest version if this exists. The (A_v) Coefficient shall be directly read from Table 4.1-2 for the capitals of provinces and important cities. For important structures in dam sites and along the Panama Canal, the values of Coefficient, Av, shall be taken from Table 4.1-3. In absence of a map of effective peak acceleration (A_a), this value shall be taken in a conservative way equal to the effective peak acceleration relative to velocity (Av). In case when specific earthquake ground motions are used or required for a site, these shall be developed based on the earthquake ground motions, which have a probability of 90 percent being, not exceed in 50 years.

4.1.4.2 **Seismic Risk Exposure Groups:** All the buildings shall be assigned to one of the following Seismic Risk Exposure Groups:

4.1.4.2.1 **Group III.** Buildings of the Group III of the Seismic Risk Exposure Group are those, which have essential facilities required to recover after the earthquake.

4.1.4.2.2 **Group II.** Buildings of the Group II of the Seismic Risk Exposure Group are those, which present a substantial risk for the public due to the occupation or its use.

4.1.4.2.3 **Group I.** Buildings being not included in the Groups III or II.

4.1.4.3 **Category of Seismic Performance**: All the buildings shall be assigned to one Category of Seismic Performance based on Table 4.1-1.

4.1.4.4 **Site Limitations for Category E of Seismic Performance.** A building assigned to Category E shall not be located on the place where a potential well-known active fault exists which causes immediate rupture of the ground surface underneath the building.

4.1.5 Materials and Alternative Methods of Constructions

4.2 Definitions and Symbols

4.2.1 Definitions

4.2.2 Symbols

A_a	=	Seismic coefficient, which represents the effective peak acceleration determined in Section 4.1.4.1.
A_v	=	Seismic coefficient, which represents the effective peak acceleration relative to the velocity, determined in Section 4.1.4.1.
A_x	=	Torsion amplification factor in Section 4.4.4.2.
a_c	=	Amplification factor related to the response of the system or component response, which is affected by the type of seismic connection, and is determined in Section 4.8.3.2.
a_d	=	Incremental factor related to the P-delta effects in Section 4.4.6.2.
C_a	=	Coefficient for the superior limit of the calculated period (refer to Table 4.4-1).
C_c	=	Seismic coefficient for buildings specified in Tables 4.8-1 and 4.8-2. (Non-dimensional)
C_d	=	Deflection amplification factor given in Table 4.3-2.
C_s	=	Seismic design coefficient in Section 4.4.2. (Non-dimensional)
C_{sm}	=	Modal coefficient of seismic design in Section 4.5.5. (Non-dimensional)
C_T	=	Building period coefficient in Section 4.4.2.2.
C_{vx}	=	Vertical distribution factor determined in Section 4.4.3.
D	=	Dead load effect.
F_i, F_n, F_x	=	Part of the seismic shear on the base, included in i-th, x-th or n-th level respectively in Section 4.4.3.
F_p	=	Seismic forces which act to the element of the building in Sections 4.3.6.1.1, 4.3.6.1.2, 4.3.6.2.7, 4.3.6.2.8, 4.8.2 or 4.8.3.
F_{xm}	=	Part of the seismic base shear force, V_m, included in x-th story level in Section 4.5.6.
g	=	Acceleration due to gravity.
h_i, h_n, h_x	=	Height over the base of i-th, x-th or n-th level respectively.
h_{sx}	=	Height below x-th level where $x=(h_x-h_{x-1})$
i	=	Building level identified by i-th sub-index; i=1 designates the first floor level above the base.
K	=	Rigidity of the device to connect the support of the equipment, Section 4.8.3.3.
k	=	Distribution exponent given in Section 4.4.3.
M_f	=	Design overturning moment of foundation defined in Section 4.4.5.
M_t	=	Design torsional moment resulted from the location of the building mass in Section 4.4.4.2.
M_{ta}	=	Accidental torsional moment determined in Section 4.4.4.2.
M_x	=	Design overturning moment of the building in x-th floor level in Section 4.4.5 or 4.5.8.
m	=	Sub-index which denotes the vibration mode in consideration, for example, m=1 for the fundamental mode.
N	=	Number of stories in Section 4.4.2.2.

n	=	Highest level of the principal part of the building.
P	=	Recovery criterion factor given in Section 4.8. (Non-dimensional)
P_x	=	Non-factored Vertical design load in and over the x-th floor level being used in Section 4.4.6.2.
Q_E	=	Horizontal seismic forces induced by the earthquake in Section 4.3.7.
R	=	Response modification coefficient given in Table 4.3-2.
S	=	Coefficient of soil profile characteristics at building site given in Table 4.3-1.
S_1, S_2, S_3, S_4	=	Soil profile types defined in Section 4.3.2.
T	=	Fundamental period of the building in Section 4.4.2.2.
T_a	=	Approximate fundamental period of the building in Section 4.4.2.2.
T_c	=	Fundamental period of a component and its connection system in Section 4.8.3.
T_m	=	Period of vibration in m-th mode in Section 4.5.4.
V	=	Design total lateral force or base shear in Section 4.4.2.
V_t	=	Design seismic base shear force in Section 4.5.8.
V_x	=	Seismic shear in x-th story in Section 4.4.4 or 4.5.8.
W	=	Total gravity load of the building in Section 4.4.2.
W_c	=	Gravity load of a building component.
W_m	=	Effective modal gravity load in Equation 4.5-2.
w_i, w_n, w_x	=	Part of W which is located or assigned to i-th, n-th or x-th floor level, respectively.
x	=	Level under consideration; x=1 designates the first floor level above the base.
Δ	=	Design horizontal displacement between stories in Sections 4.4.6.1.
Δ_a	=	Admissible horizontal displacement between stories in Sections 4.3.8.
Δ_m	=	Design horizontal displacement between stories in Sections 4.5.6.
δ_{max}	=	Maximum displacement in x-th level by considered torsional effect in Section 4.4.4.2.
δ_{prom}	=	Average displacement in extreme points of the structure in x-th level in Section 4.4.4.2.
δ_x	=	Deflection of x-th floor level at the mass center of x-th floor level in Equation 4.4-10.
δ_{xe}	=	Deflection of x-th floor level at the mass center of x-th floor level which is determined using by an elastic analysis in Section 4.4.6.1.
δ_{xem}	=	Modal deflection of x-th floor level at the mass center of x-th floor level which is determined by using an elastic analysis in Section 4.5.6.
δ_{xm}	=	Modal deflection of x-th floor level at the mass center of x-th floor level in Equation 4.5-5.
Θ	=	Stability coefficient for P-delta effects in Section 4.4.6.2.
τ	=	Overturning moment reduction factor in Equation 4.4-9.
ϕ	=	Resistance reduction factor or resistance factor.
ϕ_{im}	=	Displacement amplitude in i-th floor level of the building in case when the building with fixed base condition vibrates in m-th mode in Section 4.5.5.

4.3 Requirements for Structural Design

4.3.1 **Basis of Design.** The seismic analysis and design procedures used in the design of buildings and their components shall satisfy the requirements of this Section. The design earthquake ground motions could occur in any horizontal direction of the building. The design seismic forces and its distribution along the height of the building should be determined based on the procedures presented in Sections 4.4 or 4.5, and the corresponding internal forces shall be obtained by using the linear elastic model. An alternative procedure to establish the seismic forces and its distribution can be also used, if a proper model is adopted to the alternative procedure for determining the internal forces and the deformations of the members. The individual members shall be designed for the shears, axial forces and moments determined based on these provisions, and the connections should develop the resistance of the connected members or the forces acting there. The building deformation shall not exceed the prescribed limits when the building is subjected to the design seismic forces. The continuous load pass with enough resistance and rigidity shall be provided to transfer all the forces from the application point to the final point of resistance.

4.3.2 **Site Coefficients.** The value of site coefficient (S) shall be determined according to Table 4.3.1. In places where soil properties and sufficient details to determine the soil profile type are not known, or soil profile cannot adjust to the four types of the Table 4.3.1, the site coefficient of 2.0 shall be used. The design shear at the base (or base shear), the shear force distribution along the height of the stories, overturning moments, and deflections determined from the requirements of the sections 4.4 or 4.5 shall be modified based on Section 4.6 or others approved procedures which take into account of the soil-structure interaction effects.

4.3.3 **Structural Systems.** The basic structural systems are indicated in Table 4.3.2. Each type of the structural systems is subdivided according to the structural vertical elements used to resist seismic lateral forces. The structural system used shall be assigned to the seismic performance category and height limitations present in Table 4.3.2. The appropriate factors of response modification (R) and amplification of deflection indicated in Table 4.3.2 shall be used to determinate the base shear and the design displacement along the stories. The construction and seismic-resistant systems which are not appeared in Table 4.3.2 shall be permitted if the analytical and experimental data which can establish the dynamic characteristics are supplied, and the lateral force resistance and the energy dissipation capacity are equivalent to Table 4.3.2 for the equivalent values of the response modification factors (R). The special requirements for the construction are indicated in Sections 4.3.6, 4.10, 4.11 and 4.12 for the buildings assigned to diverse seismic performance categories.

4.3.3.1 **Dual system**: For a dual system, the moment frame shall be able to resist at least 25 percent of the design seismic forces. The resistance of the total seismic forces shall be provided by the combination of moment frame and shear walls or braced walls proportionally to their rigidities.

4.3.3.2 **Combinations of Structural Systems:** Different structural system along orthogonal axis of the building shall be permitted. The combinations of structural systems shall be accomplished according to the requirements of this Section.

4.3.3.2.1 **Factor (R) of Combination of Structural System:** The factor, R, of the response modification in the direction under consideration in any story shall not exceed the least R factor of response modification which is obtained from Table 4.3-2 for the seismic force resistant system in the same direction and above the floor.

Exception: The limit shall not be applied to the supported structural system with a weight equal to or less than 10 percent of the building weight.

4.3.3.2.2 **Requirements of Details for Combination of Structural Systems:** The requirements of details in Section 4.3.6, which is required by the highest R factor of response modification, shall be used for common structural components to the systems having different factors of response modification.

4.3.3.3 **Seismic Performance Categories, A, B and C:** The structural system to be assigned to Categories, A, B and C of the seismic performance shall satisfy the height limitations and the structural system in Table 4.3-2.

4.3.3.4 **Seismic Performance Category, D:** The structural system to the building assigned to

Category, D, of the seismic performance shall satisfy Section 4.3.3.3 and additional provisions of this Section.

4.3.3.4.1 **Increase of Height Limit of Building:** The height limit in Table 4.3-2 could be increased to 75 meters in case of the buildings with steel braced frame or cast in place concrete shear walls. In these buildings, the braced frames or shear walls in a specific plane shall not resist more than the following percent of seismic force in each direction including torsion effects:

1. 60 percent, when the braced frames or shear walls are only in the perimeter;
2. 40 percent, when some braced frames or shear walls are in the perimeter;
3. 30 percent for others arrangements.

4.3.3.4.2 **Effects of Interaction:** In case when the moment resisting frames are enclosed or fixed to more rigid elements and are not considered as a part of the seismic force resistant system, then the elements of those frames which are enclosed or fixed shall be designed so as that the behavior or failures of the elements do not affect the frame capacity to resist the vertical load or seismic force. The design must consider the effect of rigid elements in structural system on the building deformations, which correspond to the design displacement between stories, determined based on Section 4.4.6.

4.3.3.4.3 **Compatibility of Deformation:** Every structural component, which is not included in the seismic force resistant system in the direction under consideration, shall be designed to support vertical loads and to resist the induced moments as resulted of the design horizontal displacement between stories determined in Sections 4.4.6 and 4.3.8.

4.3.3.4.4 **Special Moment Frames:** It is permitted that the special moment frame, which is used but is not required by Table 4.3-2, is discontinuous and supports a most rigid system with the least value of the response modification factor, R, whenever the requirements in Sections 4.3.6.2.4 and 4.3.6.4.2 are satisfied. When Table 4.3-2 requires a special moment frame, the frame shall be continuous through the foundation.

4.3.3.5 **Seismic Performance Category, E:** The structural system of the building assigned to Category, E, of the seismic performance shall satisfy the requirements in Section 4.3.3.4 and the additional requirements and limitations of this Section. The height increase limit of Section 4.3.3.4.1 for braced frames or shear walls shall be reduced from 75 to 50 meters.

4.3.4 **Building Configuration:** The buildings shall be classified as regular or irregular in plan or in height according the criteria of this Section.

4.3.4.1 **Irregularity in Plan:** The buildings with one or more of the irregularity types given in Table 4.3.3 shall be classified as irregular in plan and shall satisfy the requirements of the remarked sections in the same table.

4.3.4.2 **Irregularity in Height:** The buildings with one or more of the irregularity types given in Table 4.3.4 shall be classified as irregular in height and shall satisfy the requirements of the remarked sections in the same table.

4.3.5 **Analysis Procedures:** For all the buildings, their structural analysis shall be performed according to the requirements of this Section. This Section presents the minimum analysis procedure, which must be satisfied. An alternative procedure with general acceptance including the use of the specific response spectrum for a site can be permitted to use if the capable authority approves the adopted procedure. The limitations of the base shear forces specified in Section 4.5.8 shall be applied to all of the above analysis.

4.3.5.1 **Seismic Performance Category, A:** The regular or irregular buildings assigned to Category, A, is exempted from the analysis for seismic forces (or need not do seismic structural analysis) when the building is assumed to be one building as a unit. The provisions in Section 4.3.6.1 shall be applicable.

4.3.5.2 **Seismic Performance Categories, B and C:** The analysis procedures in Section 4.4 shall be used for regular or irregular buildings assigned to Categories, B and C. As alternative, much more strictest analysis can be done.

4.3.5.3 **Seismic Performance Categories, D and E:** The analysis procedures identified in Table 4.3.5 shall be used for buildings assigned to Categories, D and E. As alternative, much more strictest analysis can be done.

4.3.6 Design, Requirements of Details and Load Effects of Structural Components

4.3.6.1 Seismic Performance Category, A: The design and details of the buildings assigned to Category, A, of the seismic performance shall satisfy the requirements of this Section.

4.3.6.1.1 **Connections of Load Pass:** The parts of the building between separation joints shall be interconnected so as that the seismic forces are able to pass continuously toward the resistant system, and the connections shall be able to transmit the seismic forces (F_p) induced at the connected part. Any shorter building part shall be tied to the other part of the building with the elements which have a design resistance to be able to transmit a seismic forces equal to one third (1/3) of the effective peak acceleration relative to velocity, (A_v), multiplied by the weight of the shorter part (W_c) or 5 percent of the part weight, the greater of these values. For a building, which is exempted from a complete seismic analysis according to Section 4.3.5.1, the principal wind force resistant system is considered to be a seismic force resistant system.

4.3.6.1.2 **Anchorage to Concrete and Masonry Walls:** The concrete and masonry walls shall be anchored to the roof and all the stories, which are able to give the lateral support to the wall. The anchorage provides a positive connection between walls and roof or stories. The connections shall be able to resist the greater of the following values: the seismic lateral force (F_p) induced by the wall, or 1000/2.2*9.81*3.28/1000 = 14.5 times the effective peak acceleration relative to velocity, (Av) kN per meter of wall. The walls shall be designed to resist bending moment between anchorages when the anchorage separation exceeds 1200mm.

4.3.6.2 Seismic Performance Category, B: The building design assigned to the Category, B, of the seismic performance shall satisfy the requirements of Section 4.3.6.1 for Category, A and the requirements of this Section.

4.3.6.2.1 **Effects of Load in Components:** The effects of seismic load in components shall be determined by a load analysis in accordance with Section 4.3.5, parts of Section 4.3.6.2, and Section 4.3.7. The second order effects can be included when it is applicable. When the seismic load effects exceed the forces of connection along the load pass given in Sections 4.3.6.1.1 and 4.3.6.2.2, the seismic load effects should dominate the design. The components shall satisfy the load combinations given in Chapters 7, 8, 9, 10 and 11, respectively.

4.3.6.2.2 **Opening Space:** When opening spaces exist in shear walls, diaphragms or other type of elements like slab, the reinforcement in the edges of the opening space shall be designed to transfer the stresses within the structure. The edge reinforcement shall be extended inside of the wall or diaphragm with an enough distance to develop the force in the reinforcement.

4.3.6.2.3 **Direction of Seismic Force:** This requirement shall be considered satisfactory if the design seismic forces are applied separately and independently in each one of the two orthogonal directions.

4.3.6.2.4 **Discontinuity in Vertical System:** The buildings having one discontinuity in the lateral capacity, such as Type, 5, in vertical irregularity in Table 4.3-4, shall not be more than 2 stories or 9 meters in height, where the weak story has a calculated resistance less than 65 percent of the resistance of the above story.

Exception: The limit shall not be applied when the weak story is able to resist the seismic force equal to 75 percent of the deflection amplification factor (C_d) multiplied by design force prescribed in Section 4.4.

4.3.6.2.5 **System without Redundancy**

4.3.6.2.6 **Collector Elements**

4.3.6.2.7 **Diaphragms:** The in-plane deflection in diaphragm determined by means of engineering analysis shall not exceed the permissible deflection of the adherent elements. The permissible deflection shall be the deflection, which permit to the adherent elements in order to maintain their structural integrity under individual load and to continue supporting the prescribed loads.

The story and roof diaphragms shall be designed to resist the following seismic forces: a minimum force equal to 50 percent of the effective peak acceleration relative to velocity, (A_v), multiplied by the weight of the diaphragm and their adhered elements, plus part of the seismic shear, (V_x), in that level which is necessary to transfer to the components of the earthquake resistant vertical system due a retreat or change of vertical component rigidities over and under diaphragm.

The diaphragms shall resist shear and bending stresses produced by these forces. The diaphragms have tie or strut to distribute the anchorage force to walls within diaphragm. The diaphragm connections shall be positive, mechanical or welded connections.

4.3.6.2.8 **Bearing Walls:** The exterior or interior bearing walls and their anchorage shall be designed against a normal force to the surface equal to the effective peak acceleration relative to velocity, (A_v), multiplied by the wall weight, with a minimum force equal to 10 percent of the wall weight. The interconnection of the wall elements and the connections of the supporting structural systems shall have enough ductility, rotation capacity or enough resistance to resist the contraction, thermal changes, and differential settlement of the foundations when these effects are combined with the seismic forces. The connections shall satisfy Section 4.3.6.1.2.

4.3.6.2.9 **Structures of Inverted Pendulum Type:** The structural columns or pillars of inverted pendulum type shall be designed for a bending moment at the base determined based on the procedures given in Section 4.4.

4.3.6.2.10 **Anchorage of non-structural system:** In case when Section 4.8 is required, all the parts or components of the building shall be anchored based on the seismic force (Fp) prescribed in this Section.

4.3.6.3 **Seismic Performance Category, C:** The building design assigned to Category, C, of the seismic performance shall satisfy the requirements of Section 4.3.6.2 for Category, B, and the requirements of this Section.

4.3.6.3.1 **Direction of Seismic Forces:** For buildings having the structural irregularity in plan of Type, 5, presented in Table 4.3-3, the requirement of the critical direction in Section 4.3.6.2.3 shall be considered to be "satisfied" if the components and their foundations are designed for the following orthogonal combination of prescribed loads: 100 percent of the forces in one direction plus 30 percent of the force in perpendicular direction. The combination, which requires the larger component resistance, shall be used.

4.3.6.4 **Seismic Performance Categories, D and E:** The building design assigned to Categories, D and E, of the seismic performance shall satisfy the requirements of Section 4.3.6.3 for Category, C, and the requirement of this Section.

4.3.6.4.1 **Direction of Seismic Load:** The independent orthogonal procedure given in Section 4.3.6.2.3 shall not be satisfactory for the requirement of the critical direction in any building. The procedure of orthogonal combination shown in Section 4.3.6.3.1 shall be applied to all the buildings in the present Categories.

4.3.6.4.2 **Irregularities in Plan and Height:** The design shall consider the probability of adverse effects when the relation of resistance provided in any story is significantly less than the resistance of the above story. The resistance shall be adjusted to compensate this effect.

For buildings which have a irregularity in plan of Types, 1, 2, 3, or 4 in Table 4.3-3 or a structural irregularity in height of Type, 4, in Table 4.3-4, the design forces determined based on Section 4.4 shall be increased 25 percent for diaphragm connection to vertical elements and collectors, also for the connection of collectors to vertical elements.

4.3.6.4.3 **Vertical Seismic Loads:** The vertical component of the earthquake ground motions shall be considered in the design of horizontal cantilever and the horizontal pre-stressed components. The horizontal pre-stressed component shall be designed for a load combination given by Equation 4.3.2A in Section 4.3.7. The horizontal cantilever shall be designed for an upwards-pure force equal to 0.2 times the dead load; furthermore the applicable load combinations of Section 4.3.7.

4.3.7 Combination of Load Effects: The effects of the buildings and their components due to seismic force shall be combined with the gravity loads based on the following load combinations. In these combinations, the induced force effects by earthquake shall include the vertical and horizontal effects given by Equation 4.3-1 or applied by Equations (4.3-1A), (4.3-2) or (4.3-2A):

The load combination given by (1.2 D + 1.0 E + 0.5 L) is applicable to the design of structural steel, wood and masonry by means of the load and resistance factor design (LRFD), and the load combination of (1.1)(1.2 D + 1.0 E + 0.5 L) is applicable to the resistance design of reinforced and pre-stressed concrete:

with $$E = \pm 1.0 Q_E + 0.5 A_V D \qquad (4.3\text{-}1)$$

The load combination given by (0.9 D – 1.0 E) is applicable to the design of structural steel, wood and masonry by means of load and resistance factor design (LRFD), and the load combination of (1.1)((1.1)(0.9 D –1.0 E) is applicable to the resistance design of reinforced and pre-stressed concrete:

with $$E = \pm 1.0 Q_E - 0.5 A_V D \qquad (4.3\text{-}2)$$

Where

E	=	The effect of horizontal and vertical forces induced by earthquake
A_V	=	The coefficient which represents the effective peak acceleration relative to velocity in Section 4.1.4.1
D	=	Dead load effect, D
L	=	Live load effect, L
Q_E	=	Horizontal seismic force effect

For columns which support the discontinuous elements of lateral force resistant system, the axial compression in columns shall be computed by using the load combination of (1.2 D + 1.0 E + 0.5 L), which is applicable to the design of structural steel, wood and masonry by means of the load and resistance factor design, and the combination of (1.1)(1.2 D + 1.0 E + 0.5 L) is applicable to the resistance design of reinforced and pre-stress:

in which $$E = \left(\frac{2R}{5}\right) Q_E + 0.5 A_V D \qquad (4.3\text{-}1A)$$

It is not necessary that the axial forces in these columns exceed other structural element capacity to transfer these loads to the columns.

For materials, systems and brittle connections, also following load combination of (0.9 D + 1.0 E) is used and applicable to the design of the structural steel, wood and masonry by means of the load and resistance factor design, and the combination of (1.1)(0.9 D + 1.0 E) is applicable to the resistance design of the reinforced and pre-stress concrete:

in which $$E = \left(\frac{2R}{5}\right) Q_E - 0.5 A_V D \qquad (4.3\text{-}2A)$$

In Equations (4.3-1A) and (4.3-2A), the factor (2R/5) shall be greater or equal to 1.0. The term, (0.5 A_V), in Equations (4.3-1), (4.3-1A), (4.3-2) and (4.3-2A) can be neglected when A_V is equal to or less than 0.05.

4.3.8 Limitations Deflection and Horizontal Displacements between Stories: The horizontal displacement between two adjacent stories (Δ), which is determined based on Sections 4.4.6 or 4.5.8, shall not exceed the admissible horizontal deflection between stories (Δ_a) in Table 4.3-6.

4.4 Equivalent Lateral Force Procedure

4.4.1 General: This Section provides the minimal standards required to the equivalent lateral force procedure for the seismic analysis of buildings. For the analysis purpose, the building is considered to be fixed at the base. The limitations in the utilization of this procedure are given in Section 4.3.5.

4.4.2 Seismic Shear Forces at Base: The shear force (V) at the base due to earthquake in one direction is determined according the following Equation:

$$V = C_s W \tag{4.4-1}$$

Where:

C_s = Seismic design coefficient determined according to Section 4.4.2.1.

W = Total dead load and other applied partial loads given in the followings:

1. In storage, at least the 25 percent of the story live load shall be applied. It is not necessary to take into account of the story live loads of 2.5 kN/m^2 for passenger vehicle in parking lots.
2. Where a reserve for partition load is included in the story design load, the actual partition weight or a minimum weight of 0.5 kN/m^2 shall be applied to the floor area.
3. The total weight of the permanent equipment operation and their effective contents of the recipients.

4.4.2.1 Calculation of Seismic Coefficient (C_s): When the fundamental period of the building is calculated, the seismic design coefficient (C_s) is determined by using the following equation:

$$C_s = \frac{1.2 A_v S}{R T^{2/3}} \tag{4.4-2}$$

Where:

A_V = The coefficient which represents the effective peak acceleration relative to velocity in Section 4.1.4.1

S = Coefficient for characteristics of soil profile of the building site in Table 4.3.1.

R = Response modification factor in Table 4.3.2.

T = Fundamental period of building determined from Section 4.4.2.2.

A reduction is permitted in soil-structure interaction when this is determined by using Section 4.6 or other procedure approved by the capable authority.
As alternative, it is not required to be calculated when the seismic design coefficient (C_s) shall be greater than the following equation:

$$C_s = \frac{2.5 A_a}{R} \tag{4.4-3}$$

Where:

A_a = Seismic coefficient, which represents the effective peak acceleration, determined in Section 4.1.4.1.

R = Response modification factor in Table 4.3.2.

4.4.2.2 Determination of Period: The fundamental period of the building, (T), in seconds, in the direction under consideration, shall be determined correctly on the basis of the structural properties and resistant element deformation capacities by an analysis. The fundamental period (T) used in Equation (4.4-2) shall not exceed the product of the coefficient (C_a) for the superior limit of the calculated period of Table 4.4.1 and the approximate fundamental period (T_a) determined by Equation (4.4.4).
As alternative, the fundamental period (T) shall be determined by the following Section 4.4.2.2.1.

4.4.2.2.1 Approximated fundamental period (T_a): The approximate fundamental period (T_a), in seconds, shall be determined using the following Equation:

$$C_s = C_T (3.28 h_n)^{3/4} \qquad (4.4\text{-}4)$$

Where:

- h_n = The height (meters) from the base to the highest level of the building.
- C_T = 0.035 For buildings where lateral force resisting system consists of moment-resisting steel frame which provides 100 percent of the required lateral force resistance, and the said frames are not enclosed or adhered by more rigid components which could tender to impede the deflection under seismic forces.
- C_T = 0.030 For buildings where lateral force resisting system consists of moment-resistant concrete frame which provides 100 percent of the required lateral force resistance, and the said frames are not enclosed or adhered by more rigid components which could tender to impede the deflection under seismic forces.
- C_T = 0.030 For buildings where lateral force resisting system consists of steel frame with eccentrically braces acting as unit with the moment-resistant frame.
- C_T = 0.020 For all the remaining buildings.

As alternative, it can be permitted to determined the approximate fundamental period (T_a), in seconds, by using the following equation in case when the building does not exceed 12 story in height, where lateral force resisting system consists of the moment-resisting concrete or steel frame and the height between stories are at least 3000mm.

$$T_a = 0.1\ N \qquad (4.4\text{-}4)$$

Where:

N = Total number of stories.

4.4.3 Vertical Distribution of Seismic Forces: The lateral seismic force induced in each level shall be determined using the following equations:

$$F_x = C_{vx} V \qquad (4.4\text{-}5)$$

$$C_{vx} = \frac{W_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} \qquad (4.4\text{-}6)$$

Where:

C_{vx} = Vertical distribution factor.

V	=	Design total lateral force or shear at the base of the building.
w_i, w_x	=	Part of the total gravity load (W) of the building located in i-th or x-th floor level.
h_i, h_x	=	The height (meters) from the base to the i-th or x-th floor level.
k	=	Exponent related to the building according to: for buildings with a period equal to or less than 0.5 second, k=1. for buildings with a period equal to or greater than 2.5 seconds, k=2. for buildings with a period between 0.5 and 2.5 seconds, k=2, or shall be determined using linear interpolation between 1 and 2.

4.4.4 Horizontal Distribution of Shear Force: The design seismic shear force between stories (V_x) shall be determined using the following equation:

$$V_x = \sum_{i=1}^{n} F_i \qquad (4.4\text{-}7)$$

Where:

V_x = Part of the base shear (V) induced in i-th level.

4.4.4.1 Direct Shear

4.4.4.2 Torsion

4.4.5 Overturning

4.4.6 Calculation of Horizontal Displacement between Stories and P-delta Effects:

4.4.6.1 Determination of Horizontal Displacement between Stories:

4.4.6.2 P-delta Effects:

4.5 Modal Analysis Procedure:

4.6 Soil-Structure Interaction: The effect of soil-structure interaction, which is determined by using a generally accepted procedure and approved by a capable authority, can be incorporated in the determination of the design seismic forces and the correspondent building displacements.

Editorial Notes: This manuscript is an unauthorized translation from Spanish to English languages, which is performed and prepared by Tania Croston, a Graduate Student of Oita University, JAPAN, who is from the Republic of Panama. Also the manuscript is partially revised and modified by Koji Yoshimura, a Professor of Structural Engineering of Oita University, JAPAN in November 1999.
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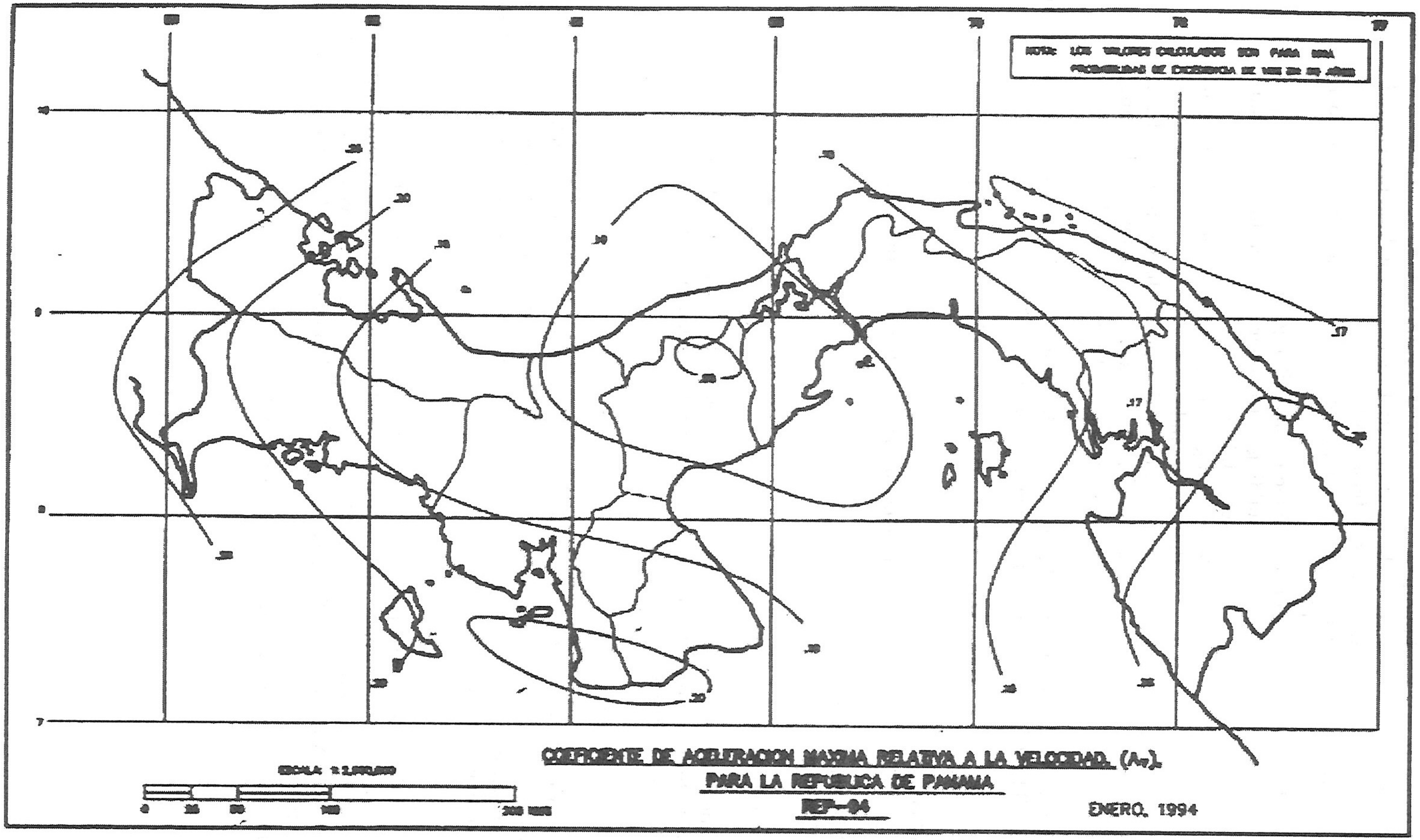

Figure 1. Coefficient of Maximum Acceleration relative to Velocity (A_v)

Table 4.1-1

Seismic Performance Categories

A_v Value	Group of Seismic Risk Exposure I	II	III
$A_v < 0.05$	A	A	A
$0.05 \leq A_v < 0.10$	B	B	C
$0.10 \leq A_v < 0.15$	C	C	C
$0.15 \leq A_v < 0.20$	C	C	D
$0.20 \leq A_v$	D	D	E

Table 4.1-2

Coefficient of effective peak acceleration relative to velocity (A_v)

for capitals of provinces and important cities of The Republic of Panama

(Exceeding probability of 10% in 50 years)

	City or Location	A_v
1	Changuinola	0.25
2	Puerto Armuelles	0.24
3	Almirante	0.21
4	Bocas del Toro	0.21
5	Tonosi	0.20
6	Jaque	0.20
7	El Real	0.20
8	Puerto Obaldia	0.19
9	David	0.18
10	La Palma	0.18
11	Aligandi	0.17
12	Boquete	0.16
13	Las Tablas	0.15
14	Sona	0.15
15	Portobelo	0.14
16	Santiago	0.13
17	Chitre	0.13
18	Colon	0.12
19	PANAMA	0.11
20	Aguadulce	0.10
21	Chorrera	0.09
22	Playa Coronado	0.08
23	El Valle	0.08
24	Penonome	0.08

Table 4.1-3

Coefficient of effective peak acceleration relative to velocity (A_v)

for dam and Panama canal sites.

(Exceeding probability of 5% in 100 years)

	Location	A_v
1	Bayano	0.22
2	Fortuna	0.20
3	Madden	0.16
4	Miraflores Lock	0.15
5	Pedro Miguel Lock	0.15
6	Gatun Lock	0.15

Table 4.3-1

Site Coefficient

Type of Soil Profile	Description	Site Coefficient: S
S_1	A soil profile with either: Rock of any characteristic, whether shaty or crystalline, which has a shear wave velocity greater than 750 m/sec. Rigid soil conditions where the soil depth is less than 60 meters, and the soil types over the rock are stable deposits of sand, gravel or stiff clay.	1.0
S_2	A soil profile with deep non-cohesive conditions or rigid clay, where the soil depth exceeds 60 meters, and the soil types over the rock is stable deposits of sand, gravel or stiff clay.	1.2
S_3	A soil profile containing from 6 to 12 meters of soft or medium-stiff clay with or without intermediate non-cohesive soils layer.	1.5
S_4	A soil profile characteristics for a shear wave velocity less than 150m/sec which contains more than 12 meters of soft clay or limos.	2.0

Table 4.3-2

Structural Systems

Basic Structural System And Seismic Force Resistant System	R_a[a]	C_d[b]	Limitation of the structural system and height[c] (meters) Seismic Performance Category			
			A, B	C	D[d]	E[e]
<u>Bearing Wall system</u>						
Light frame with shear panels	6.5	4.0	NL	NL	50	30
Reinforced concrete shear walls	4.5	4.0	NL	NL	50	30
Reinforced masonry shear walls	3.5	3.0	NL	NL	50	30
Braced concentrically frames	4.0	3.0	NL	NL	50	[f]
Unreinforced masonry shear walls	1.25	1.25	NL	[g]	NL	NL
<u>Building frame system</u>						
Eccentrically braced frames, moment resisting connection in columns far away to the link.	8	4	NL	NL	50	30
Braced eccentrically frames, non-moment resisting connection in columns far away to the link.	7	4	NL	NL	50	30
Light frame with shear panels	7	4.5	NL	NL	50	30
Braced concentrically frames	5	4.5	NL	NL	50	[6]
Reinforced concrete shear walls	5.5	5	NL	NL	50	30
Reinforced masonry shear walls	4.5	4	NL	NL	50	30
Unreinforced masonry shear walls	1.5	1.5	NL	NL	NP	NP
<u>Moment resisting frame system</u>						
Steel special moment frames	8	5.5	NL	NL	NL	NL
Reinforced concrete special moment frames	8	5.5	NL	NL	NL	NL
Reinforced concrete intermediate moment frames	4	3.5	NL	NL	NP	NP
Steel simple moment frames	4.5	4	NL	NL	50	30
Reinforced concrete simple moment frames	2	2	NL	NP	NP	NP
<u>Dual system with special moment frame to be able to resist at least 25% of the prescribed seismic forces</u>						
Braced eccentrically frames, moment resisting connection in columns far away to the link.	8	4	NL	NL	NL	NL
Eccentrically braced frames, non-moment resisting connection in columns far away to the link.	7	4	NL	NL	NL	NL
Concentrically braced frames	6	5	NL	NL	NL	NL
Reinforced concrete shear walls	8	6.5	NL	NL	NL	NL
Reinforced masonry shear walls	6.5	5.5	NL	NL	NL	NL
Shear panels covered with wood	8	5	NL	NL	NL	NL

[a] Coefficient of response modification, R, is used in Sections4.3.55, 4.4.2.1, 4.5.5 and other section.

[b] Deflection amplification factor, C_d, is used in Sections 4.4.6.1 and 4.4.6.2.

[c] NL= not limited and NP=Not permitted

[d] For description of limited building system with height equal or less than 72 meters, the reference is in Section 4.3.3.4.1.

[e] For limited building system with height equal or less than 50 meters, the reference is in Section 4.3.3.5.

[f] A braced concentrically frame in building with more than one story shall form part of a dual system.

[g] The masonry shear walls will have nominal reinforced according is required in ACI-ASCE 530.

Dual system with intermediate moment frame to be able to resist at least 25% of the prescribed seismic forces						
Concentrically braced frames	5	4.5	NL	NL	50	30
Reinforced concrete shear walls	6	5	NL	NL	50	30
Reinforced masonry shear walls	5	4.5	NL	NL	50	30
Shear Panels covered with wood	7	4.5	NL	NL	50	30
Seismic force resistant system of inverted pendulum structure type						
Structural steel special moment frame	2.5	2.5	NL	NL	NL	NL
Reinforced concrete special moment frame	2.5	2.5	NL	NL	NL	NL
Structural steel simple moment frame	1.25	1.25	NL	NL	NP	NP

Table 4.3-3

Plan Structural Irregularities

	Irregularity Type and definition	Reference Section	Seismic Performance Category
1.	The torsional irregularity shall be considered when the diaphragms are not flexible. The 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 time the average of the story drifts of the two ends of the structure.	4.3.6.4.2 4.4.4.2	D and E C, D and E
2.	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 15 % of the plan dimension in the given direction.	4.3.6.4.2	D and E
3.	Diaphragm Discontinuity Diaphragm with abrupt discontinuities or variations in stiffness, including those having cutout or open area greater than 50 % of the gross enclosed area of the diaphragm, or changes in effective diaphragm stiffness of more than 50% from one story to the next.	4.3.6.4.2	D and E
4.	Out-of-plane offsets Discontinuities in lateral force path, such as out-of-plane offsets of vertical elements that resist the seismic lateral forces.	4.3.6.4.2	D and E
5.	Nonparallel Systems The vertical lateral load-resisting elements are not parallel to or symmetric above the major orthogonal axes of lateral force-resisting system.	4.3.6.3.1	C, D and E

Table 4.3-4

Vertical Structural Irregularities

	Irregularity Type and definition	Reference Section	Seismic Performance Category
1.	Stiffness Irregularity: soft story The soft story is one in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average stiffness of the three stories above.	4.3.5.3	D and E
2.	Weight (mass) irregularity Mass irregularity shall be considered to exist where the effective mass of any story is more than 150% of the effective mass of an adjacent story. A roof, which is lighter than the floor below, need not be considered.	4.3.5.3	D and E
3.	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% of that in an adjacent story.	4.3.5.3	D and E
4.	In-plane discontinuity in vertical lateral-force-resisting elements An in-plane offset of the lateral load resisting elements greater than the length of those elements.	4.3.6.4.2	D and E
5.	Discontinuity in capacity: weak story A weak story is one in where the story strength is lesser than 80% of that in the story above. The story strength is the total strength of all the seismic-resisting elements sharing the story shear for the direction under consideration.	4.3.6.2.4 4.3.6.4.2	B, C, D and E

Table 4.3-5

Analysis procedure

For Seismic Performance Categories, D and E.

Building Description	Reference Section and Procedures
1. Buildings designed as regular which does not exceed 72 meters in height.	Section 4.4
2. Buildings with only vertical irregularities of Types, 1, 2 and 3 in Table 4.3-4 and have a height of more than 5 stories or 20 meters, and all building with more than 72 meters in height.	Section 4.5
3. The remaining buildings with vertical irregularities or irregularities in plan.	Section 4.4 and the irregularity effects in dynamic response.
4. Building in Groups, II and III, of Seismic risk Exposure in areas where A_a is greater than 0.40, inside 10 kilometers of failures which have the possibility to generate earthquake of magnitude equal or greater than 7.	A specific response spectrum shall be used for a site, but the design base shear shall not be less than the value determined in Section 4.4.2.
5. Building in area with Av equal or greater than 2 with a building period equal or greater than 0.7 second, located on Soil Type, S_4.	A specific response spectrum shall be used for a site, but the design base shear shall not be less than the value determined in Section 4.4.2. The Modal Seismic Design Coefficient, C_{sm}, shall not be limited by Section 4.5.5.

Table 4.3-6

Permissible Horizontal Displacement between Stories (D_a)[1]

Building	Group of Seismic Risk Exposure I	II	III
Building with one story in height without fixed equipment to the structural resistant system and with interior walls, partitions, flat ceiling, and exterior wall systems which are designed to accommodate the horizontal displacement between stories.	Without Limit	$0.020h_{sx}$	$0.015h_{sx}$
Building with four story or less in height with interior walls, partitions, flat ceiling, and exterior wall systems which are designed to accommodate the horizontal displacement between stories.	$0.025h_{sx}$	$0.020h_{sx}$	$0.015h_{sx}$
The other buildings.	$0.020h_{sx}$	$0.020h_{sx}$	$0.010h_{sx}$

Table 4.4-1

Coefficient for Upper Limit of Calculated Period

Coefficient which represents Effective Peak Acceleration relative to Velocity, (A_v)	Coefficient C_a
0.40	1.2
0.30	1.3
0.20	1.4
0.15	1.5
0.10	1.7
0.05	1.7

[1] h_{sx}=The height of the story under the x-th level