0306 SEISMIC LOADS

0306.1 GENERAL

Every structure, and portion thereof, including nonstructural components such as architectural, mechanical, and electrical components, shall be designed and constructed to resist the effects of earthquake motions determined in accordance with this section.

0306.1.1 Additions to Existing Buildings

0306.1.1.1 Independent Addition

An addition that is structurally independent from an existing structure shall be designed and constructed as required for a new structure in accordance with this section.

0306.1.1.2 Dependent Addition

An addition that is not structurally independent from an existing structure shall be designed and constructed such that the entire structure complies with the seismic force resistance requirements for new structures unless the addition does not increase the seismic forces in any structural element of the existing structure by more than 5 percent.

0306.1.2 Change of Occupancy

When a change of occupancy results in a structure being reclassified to a higher occupancy category in Section 0103 the structure shall comply with the seismic requirements for a new structure.

0306.1.3 Alterations.

When the alteration increases the seismic forces in any structural element of the existing structure by more than 5 percent, the elements shall conform to the seismic requirements for a new structure.

0306.2 LOAD COMBINATIONS

0306.2.1 Strength Design

Where strength design or load and resistance factor design is used, the seismic load factor in the load combinations applied to each design shall be equal to 1.0.

0306.2.2 Allowable Stress Design

Where allowable stress design is used, the seismic load factor in load combinations including seismic loads shall be taken equal to 0.7. In this case, an allowable stress is permitted to be increased in accordance with each material reference standard.

0306.2.3 Special Seismic Load

In the design of a structural member such as a piloti, where failure of this member can result in overall structural instability or collapse and rapid change of the seismic load path, the special seismic load, E_m, shall be used in the seismic load combinations instead of the seismic load, E.

$$E_m = \Omega_0 E \pm 0.2 S_{DS} D \qquad (0306.2.1)$$

where Ω_0 is the system overstrength factor as given in <Table 0306.6.1>. SDS is the design spectral response acceleration at short periods obtained from Section 0306.3.3 and D is the effect of dead load. The term $\Omega_0 E$ need not exceed the maximum force that can be transferred to the element by the other elements of the lateral force resisting system.

Where allowable stress design is used with the special seismic load applied in load combinations, design strengths are permitted to be determined using an allowable stress increase of 1.7 and a resistance factor, ϕ, of 1.0. This increase shall not be combined with increases in any other allowable stresses or load combination reductions

0306.3 DETERMINATION OF SEISMICITY

0306.3.1 Region of Seismicity and Spectral Acceleration Parameter

The region of seismicity in Korea and the corresponding values of the spectral response acceleration parameters, S, shall be classified as <Table 0306.3.1>

〈TABLE 0306.3.1〉 REGION OF SEISMICITY AND SPECTRAL ACCELERATION PARAMETER

Region of Seismicity	Administrative District	S
1	All region with the exception of 2	0.22
2	North Gangwon-do, Southwestern Jeollanam-do, Jeju-do	0.14

※ North Gangwon-do: Hongcheon, Cheorwon, Hwhacheon, Hoengseong, Pyeongchang, Yanggu, Inje, Goseong, Yangyang, Chuncheon-si, Sokcho-si. Southwestern Jeollanam-do: Muan, Shinan, Wando, Yeonggwang, Jindo, Haenam, Yeongam, Gangjin, Goheung, Hampyeong, Mokpo-si

0306.3.2 Site Classification

0306.3.2.1 Site Class

The site shall be classified as five Site Classes defined in <Table 0306.3.2> to consider the effect of limited geologic conditions and soil properties on ground motion. Where the soil properties are not known in sufficient detail to determine the Site Class, Site Class S_D shall be used unless Site Class S_E is likely to be present at the site.

〈TABLE 0306.3.2〉 SITE CLASSIFICATION

Site Class	Soil profile name	Average properties on the upper 30m of the site profile		
		Shear wave velocity (m/s)	Standard penetration resistance, $\overline{N}$ (blows/300mm)	Soil undrained shear strength, $\overline{S_U}$ ($\times 10^{-3}$MPa)
S_A	Hard rock	>1500	–	–
S_B	Rock	760 to 1500		
S_C	Very dense soil and soft rock	360 to 760	>50	>100
S_D	Stiff soil	180 to 360	15 to 50	50 to 100
S_E	Soft soil	<180	<15	<50

0306.3.2.2 Base Level for Site Classification

In general, the base level for site classification can be represented by the ground surface. For structures with direct foundation on firm ground such as Site Class S_C or higher Site Classes, the foundation surface can be considered as the base level for site classification. The safety of superstructures shall not be affected by the lateral soil pressure that applies to structural walls in the basement during earthquake. When pile foundation is constructed, the ground surface is considered as the base level.

0306.3.3 Design Spectral Acceleration Parameters

The design spectral response acceleration parameter at short period, S_{DS}, and at 1 second period, S_{D1}, shall be determined by the following equations.

$$S_{DS} = S \times 2.5 \times F_a \times 2/3 \quad (0306.3.1)$$

$$S_{D1} = S \times F_v \times 2/3 \quad (0306.3.2)$$

where site coefficients F_a and F_v are defined in <Table 0306.3.3> and <Table 0306.3.4>, respectively. The mapped maximum considered earthquake spectral response acceleration, S, with a 2400 year mean recurrence interval can be obtained using <Table 0306.3.1> or the seismic hazard map in [Figure 0306.3.1].

The parameter S determined using the seismic hazard map shall be greater than or equal to 80 percent of S determined from <Table 0306.3.1>.

〈TABLE 0306.3.3〉 SITE COEFFICIENT, F_a

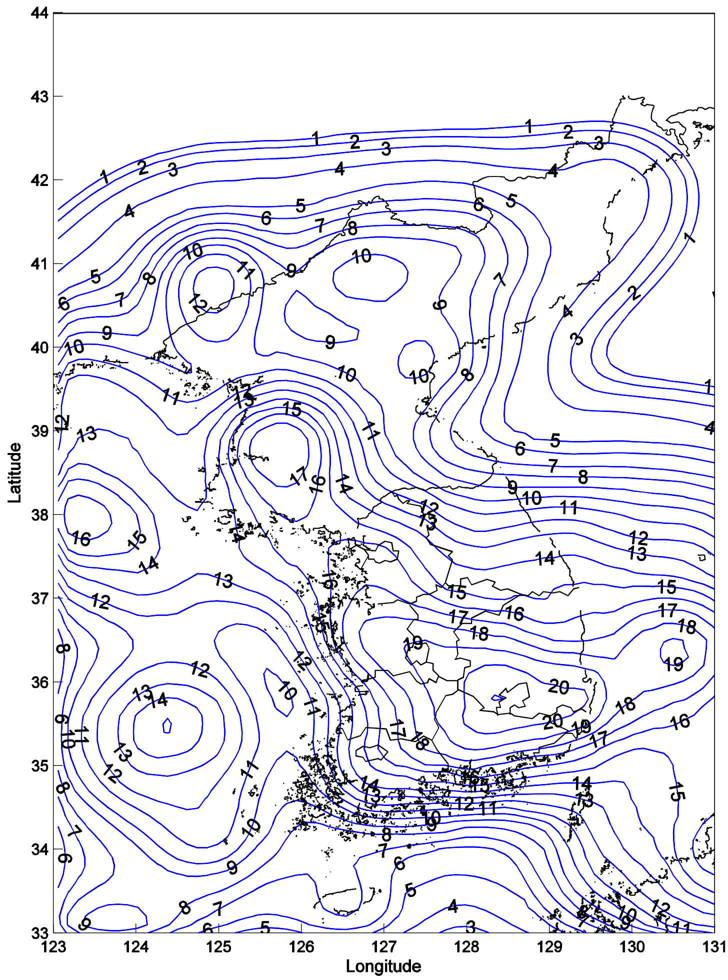
Site Class	Region of Seismicity		
	$S_s \le 0.25$	$S_s = 0.50$	$S_s = 0.75$
S_A	0.8	0.8	0.8
S_B	1.0	1.0	1.0
S_C	1.2	1.2	1.1
S_D	1.6	1.4	1.2
S_E	2.5	1.9	1.3

* The value of S_s shall be determined by multiplying S in 〈Table 0306.3.1〉 by 2.5. The straight line interpolation is applied for intermediate values of S_s.

〈TABLE 0306.3.4〉 SITE COEFFICIENT, F_v

Site Class	Region of Seismicity		
	$S \leqq 0.1$	$S=0.2$	$S=0.3$
S_A	0.8	0.8	0.8
S_B	1.0	1.0	1.0
S_C	1.7	1.6	1.5
S_D	2.4	2.0	1.8
S_E	0.8	0.8	0.8

* The value of S is indicated in 〈Table 0306.3.1〉. The straight line interpolation is applied for intermediate values of S.



[FIGURE 0306.3.1] MAXIMUM CONSIDERED EARTHQUAKE (MCE) GROUND MOTION OF THE MAPPED SPECTRAL RESPONSE ACCELERATION WITH A 2400-YEAR MEAN RECURRENCE INTERVAL ; SEISMIC DESIGN STANDARD RESEARCH II (MINISTRY OF CONSTRUCTION AND TRANSPORTATION, 1997)

In addition, site specific geotechnical investigation and dynamic site response analyses shall be performed to determine the values of F_a and F_v. In this case, the design spectral response acceleration parameters S_{DS} and S_{D1} obtained shall not be taken less than 80 percent of the values determined from <Table 0306.3.1>, <Table 0306.3.3>, and <Table 0306.3.4>.

0306.3.4 Design Response Spectrum

The design response spectrum of the earthquake ground motion shall be determined in accordance with the following equations and developed as indicated in [Figure 0306.3.2].

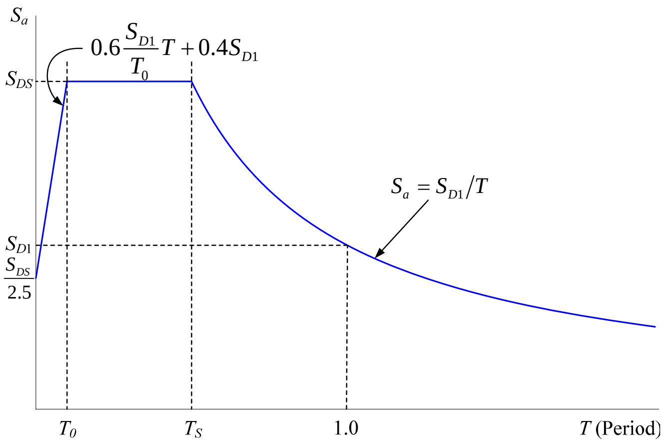
(1) For $T \leqq T_0$, the design spectral response acceleration, S_a, shall be taken as given by Equation (0306.3.3).

(2) For $T_0 \leqq T \leqq T_S$, the design spectral response acceleration, S_a, shall be taken as equal to SDS.

(3) For $T > T_S$, the design spectral response acceleration, S_a, shall be taken as given by Equation (0306.3.4).

$$S_a = 0.6\frac{S_{DS}}{T_o}T + 0.4S_{DS} \qquad (0306.3.3)$$

$$S_a = \frac{S_{D1}}{T} \qquad (0306.3.4)$$



[FIGURE 0306.3.2] DESIGN RESPONSE SPECTRUM where, T : the fundamental period of the structure (seconds)

$$T_o = 0.2\,S_{D1}/S_{DS}$$

$$T_S = S_{D1}/S_{DS}$$

0306.4 CALCULATION OF SEISMIC LOADS

0306.4.1 General

Each structure shall be assigned a Seismic Design Category based on its occupancy and site conditions. Seismic Design Categories are used in this code to determine permissible structural systems, limitations on height and irregularity, those components of the structure that must be designed for seismic resistance, and the types of lateral force analysis that must be performed.

0306.4.2 Seismic Use Groups and Occupancy Importance Factors

Each structure shall be assigned a Seismic Use Group and an Occupancy Importance Factor based on the importance of the building structures in accordance with <Table 0306.4.1>. Where a structure is occupied for two or more occupancies not included in the same Importance, the structure shall be assigned the classification of the highest Importance corresponding to the various occupancies. However, where structures have two or more portions that are structurally separated in accordance with Section 0306.8, each portion shall be separately classified. Where a structurally separated portion of a structure provides required access to, required egress from, or shares life safety components with another portion having a higher Importance, both portions shall be assigned the higher Importance.

〈TABLE 0306.4.1〉 SEISMIC USE GROUPS AND IMPORTANCE FACTORS

Importance of the Building Structure	Seismic Use Group	Importance Factor (I_E)
Importance (S)	(S)	1.5
Importance (1)	I	1.2
Importance (2), (3)	II	1.0

0306.4.3 Determination of Seismic Design Category

All structures shall be assigned to a Seismic Design Category in accordance with <Table 0306.4.2> or <Table 0306.4.3> based on their Seismic Use Group, determined in accordance with Section 0306.4.2, and the design spectral response acceleration, SDS and SD1, determined in accordance with Section 0306.3.3. If Seismic Design Categories determined according to <Table 0306.4.2> and <Table 0306.4.3> are different, the most severe Seismic Design Category shall be used.

〈TABLE 0306.4.2〉 SEISMIC DESIGN CATEGORY BASED ON SHORT PERIOD RESPONSE ACCELERATIONS

Value of S_{DS}	Seismic Use Group		
	(S)	I	II
$0.50 \leq S_{DS}$	D	D	D
$0.33 \leq S_{DS} < 0.50$	D	C	C
$0.17 \leq S_{DS} < 0.33$	C	B	B
$S_{DS} < 0.17$	A	A	A

〈TABLE 0306.4.3〉 SEISMIC DESIGN CATEGORY BASED ON 1 SECOND PERIOD RESPONSE ACCELERATIONS

Value of S_{D1}	Seismic Use Group		
	(S)	I	II
$0.20 \leqq S_{D1}$	D	D	D
$0.14 \leqq S_{D1} < 0.20$	D	C	C
$0.07 \leqq S_{D1} < 0.14$	C	B	B
$S_{D1} < 0.07$	A	A	A

0306.4.4 Building Configuration

Buildings shall be classified as regular or irregular, based on the plan and vertical configuration, in accordance with the criteria in this section.

0306.4.4.1 Plan Irregularity

Buildings having one or more of the features listed in <Table 0306.4.4> shall be designated as having plan structural irregularity.

0306.4.4.2 Vertical Irregularity

Buildings having one or more of the features listed in <Table 0306.4.5> shall be designated as having vertical irregularity. However, there are exceptions to the criteria where one of the following conditions is satisfied.

(1) Structural irregularities of Type V-1 or V-2 in <Table 0306.4.5> do not apply where no story drift ratio under design lateral load is greater than 130 percent of the story drift ratio of the next story above. Torsional effects need not be considered in the calculation of story drifts for the purpose of this determination. Also, the story drift ratio relationship for the top two stories of the building are not required to be evaluated.

(2) Irregularities Type V-1 and V-2 of <Table 0306.4.5> are not required to be considered for one story or two-story buildings assigned to any Seismic Design Category.

0306.4.5 Analysis Procedures

A structural analysis in accordance with the requirements of this section shall be made for all structures, based on the assigned Seismic Design Category.

0306.4.5.1 Analysis Procedures for Seismic Design Category A or B

The equivalent lateral force procedure in Section 0306.5 shall be used for structures assigned to Seismic Design Category A or B.

0306.4.5.2 Analysis Procedures for Seismic Design Category C

The equivalent lateral force procedure in Section 0306.5 shall be used for structures assigned to Seismic Design Category C. However, the dynamic analysis procedure shall be used in cases where one of the following conditions is satisfied.

(1) Regular structures that have a height exceeding 70 meters or twentystories

(2) Irregular structures that have a height exceeding 20 meters or six stories

0306.4.5.3 Analysis Procedures for Seismic Design Category D

The analysis procedures identified in <Table 0306.4.6> shall be used for structures assigned to Seismic Design Category D, or a more rigorous analysis shall be made. Structures shall be considered regular if they do not have plan irregularities H-1 or H-4 of <Table 0306.4.4> or vertical irregularities V-1, V-4 or V-5 of <Table 0306.4.5>.

〈TABLE 0306.4.4〉 PLAN STRUCTURAL IRREGULARITIES TYPE AND DEFINITION

<table>
<tr><th>Number of Type</th><th>Type</th><th>Definition</th><th>Reference Section</th><th>Seismic Design Category Application</th></tr>
<tr><td rowspan="3">H-1</td><td rowspan="3">Torsional Irregularity</td><td rowspan="3">Torsional irregularity is considered when diaphragms are not flexible. It 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 at the two ends of the structure.</td><td>0306.5.6.4</td><td>C, D</td></tr>
<tr><td>〈Table 0306.4.6〉</td><td>D</td></tr>
<tr><td>0306.5.7.1</td><td>C, D</td></tr>
<tr><td>H-2</td><td>Re-entrant Corners</td><td>Plan configurations of a structure and its lateral force-resisting system contain re-entrant corners, where both projections of the structure beyond a re-entrant corner are greater than 15 percent of the plan dimension of the structure in the given direction.</td><td>–</td><td>–</td></tr>
<tr><td>H-3</td><td>Diaphragm Discontinuity</td><td>Diaphragms with abrupt discontinuities or variations in stiffness, including those having cutout or open areas greater than 50 percent of the gross enclosed diaphragm area, or changes in effective diaphragm stiffness of more than 50 percent from one story to the next.</td><td>–</td><td>–</td></tr>
<tr><td>H-4</td><td>Out-of-Plane Offsets</td><td>Discontinuities in a lateral force resistance path, such as out-of-plane offsets of the vertical elements.</td><td>0306.8.3</td><td>B, C, D</td></tr>
<tr><td rowspan="2">H-5</td><td rowspan="2">Nonparallel Systems</td><td rowspan="2">The vertical lateral force-resisting elements are not parallel to or symmetric about the major orthogonal axes of the lateral force-resisting system.</td><td>0306.8.4.2</td><td>C</td></tr>
<tr><td>0306.8.4.3</td><td>D</td></tr>
</table>

〈TABLE 0306.4.5〉 VERTICAL STRUCTURAL IRREGULARITIES TYPE AND DEFINITION

Number of Type	Type	Definition	Reference Section	Seismic Design Category Application
V-1	Stiffness Irregularity-Soft Story	A soft story is one in which the lateral stiffness is less than 70 percent of that in the story above or less than 80 percent of the average stiffness of the three stories above.	〈Table 0306.4.6〉	D
V-2	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. However, a roof that is lighter than the floor below need not be considered.	〈Table 0306.4.6〉	D
V-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 percent of that in an adja-cent story.	〈Table 0306.4.6〉	D
V-4	In-plane Discontinuity in Vertical Lateral Force-Resistin g Elements	An in-plane offset of the lateral force-resisting elements greater than the length of those elements or a reduction in stiffness of the resisting element in the story below.	0306.8.3	B, C, D
V-5	Discontinuity in Capacity-Weak Story	A weak story is one in which the story lateral strength is less than 80 percent of that in the story above. The story strength is the total strength of seismic-resisting elements sharing the story shear for the direction under consideration.	0306.8.1	B, C, D

〈TABLE 0306.4.6〉 ANALYSIS PROCEDURES FOR SEISMIC DESIGN CATEGORY 'D'

Structure Configuration	Analysis Procedure For Seismic Design
1. Seismic Use Group II: buildings of light-framed construction not exceeding three stories in height and buildings of other construction not exceeding two stories in height with flexible diaphragms at every level.	Equivalent lateral force procedure or Dynamic analysis procedure
2. Regular structures, other than those of the above criteria (1), not exceeding 70 meters in height.	Equivalent lateral force procedure or Dynamic analysis procedure
3. Structures that have vertical irregularities Type V-1, V–2 or V–3 in 〈Table 0306.4.5〉 or plan irregularities Type H-1 of 〈Table 0306.4.4〉 and have a height exceeding five stories or 20 meters; and regular structures exceeding 70 meters in height.	Dynamic analysis procedure
4. Other structures designated as having plan or vertical irregularities.	Dynamic analysis procedure

0306.4.6 Deflection and Drift Limits

The design story drift, Δ, as determined in Section 0306.5.7, shall not exceed the allowable story drift, Δ_a, as obtained from <Table 03064.7> for any story.

〈TABLE 0306.4.7〉 ALLOWABLE STORY DRIFT, Δ_a

	Seismic Use Group		
	(S)	I	II
Allowable Story Drift, Δ_a	$0.010h_{sx}$	$0.015h_{sx}$	$0.020h_{sx}$

h_{SX} : the story height below level x

0306.5 EQUIVALENT LATERAL FORCE PROCEDURE

0306.5.1 Seismic Base Shear

The seismic base shear, V, shall be determined in accordance with the following equation:

$$V = C_s\ W \qquad (0306.5.1)$$

where

C_s : The seismic response coefficient determined in accordance with Section 0306.5.2.

W : The effective seismic weight of the structure, including the total dead load and other loads listed below

① In areas used for storage, a minimum of 25 percent of the floor live load. (Floor live load in public garages and open parking structures need not be included.)

② Where an allowance for partition load is included in the floor load design, the actual partition weight or a minimum weight of 0.5 kN/㎡ of floor area, whichever is greater.

③ Total operating weight of permanent equipment.

④ Twenty percent of flat roof snow load where the flat roof snow load exceeds 1.5 kN/㎡.

0306.5.2 Seismic Response Coefficient

The seismic response coefficient, C_s, shall be determined in accordance with the following equation.

$$C_s = \frac{S_{D1}}{\left[\frac{R}{I_E}\right] T} \qquad (0306.5.2)$$

The value of the seismic response coefficient, C_s, computed in accordance with Equation (0306.5.2) need not exceed the following.

$$C_s = \frac{S_{DS}}{\left[\frac{R}{I_E}\right]} \qquad (0306.5.3)$$

but shall not be taken less than the following value.

$$C_s = 0.01 \qquad (0306.5.4)$$

where

I_E : The occupancy importance factor determined in accordance with <Table 0306.4.1>

R : The response modification factor from <Table 0306.6.1>

S_{DS} : The design spectral response acceleration at short period as determined in Section 0306.3.3

S_{D1} : The design spectral response acceleration at 1 second period as determined from Section 0306.3.3

T : The fundamental period of the building (in seconds) determined in Section 0306.5.3

0306.5.3 Period Determination

The fundamental period of the building in the direction under consideration shall be taken as the approximate fundamental period, T_a, determined in accordance with the requirements of Section 0306.5.4 or shall be established using the structural properties and deformational characteristics of the resisting elements in a properly substantiated analysis. The calculated fundamental period, T, shall not exceed the product of the coefficient for upper limit on calculated period, C_u, from <Table 0306.5.1> and the approximate fundamental period, T_a.

〈TABLE 0306.5.1〉 COEFFICIENT FOR UPPER LIMIT ON CALCULATED PERIOD, C_u

S_{D1}	C_u
0.4 or more	1.4
0.3	1.4
0.2	1.5
0.15	1.6
0.1 or less	1.7

0306.5.4 Approximate Fundamental Period

The approximate fundamental period, T_a, in seconds, shall be determined from the following equation:

$$T_a = C_T h_n^{3/4} \qquad (0306.5.5)$$

where

$C_T = 0.085$: Steel moment resisting frames

$= 0.073$: Concrete moment resisting frames, Eccentrically braced steel frames

$= 0.049$: All other structural systems

h_n = The height in meters above the base to the highest level of the structure

Alternatively, the approximate fundamental period, T_a, is permitted to be determined from the following equation for concrete or steel moment resisting frame structures not exceeding 12 stories in height and having minimum story height of not less than 3 m :

$$T_a = 0.1N \qquad (0306.5.6)$$

where, N : Number of stories.

The approximate fundamental period, T_a, for masonry or concrete shear wall structures is permitted to be determined from Equation (0306.5.5) or (0306.5.7).

$$T_a = 0.0743\,(h_n)^{3/4} / \sqrt{A_c} \qquad (0306.5.7)$$

$$A_c = \Sigma A_e\,[0.2 + (D_e/h_n)^2]$$

$$D_e/h_n \leq 0.9$$

where

A_e : Web area, in square meters, of shear wall parallel to the direction of the seismic load at first level

D_e : Length, in meters, of shear wall parallel to the direction of the seismic load at first level

0306.5.5 Vertical Distribution of Seismic Forces

The lateral force, F_x, induced at any level shall be determined from the following equation:

$$F_x = C_{vx} V \qquad (0306.5.8)$$

$$C_{vx} = \frac{w_x\ h_x^k}{\sum_{i=1}^{n} w_i\ h_i^k} \qquad (0306.5.9)$$

where

C_{vx} : Vertical distribution factor

k : An exponent related to the fundamental period of the structure as follows:

$k = 1$: Structures having a period of 0.5 seconds or less

$k = 2$: Structures having a period of 2.5 seconds or more

For structures having a period between 0.5 and 2.5 seconds, k shall be determined by linear interpolation between 1 and 2.

h_i, h_x : The height from the base to level i or x

V : Total design lateral force or shear at the base of the structure

w_i, w_x : The portion of the total effective seismic weight of the structure located or assigned to level i or x

n : Number of stories

0306.5.6 Horizontal Shear Distribution

The seismic story shear in any story, Vx, shall be determined from the following equation:

$$V_x = \sum_{i=x}^{n} F_i \qquad (0306.5.10)$$

where,

F_i : The portion of the seismic base shear, V, induced at level i.

0306.5.6.1 Rigid Diaphragm

For rigid diaphragms, the seismic design story shear, V_x, shall be distributed to the vertical elements of the seismic force-resisting system in the story under consideration based on the relative lateral stiffness of the vertical resisting elements and the diaphragm.

0306.5.6.2 Flexible Diaphragm

For flexible diaphragms, the seismic design story shear, V_x, shall be distributed to the vertical elements of the seismic force-resisting system in the story under consideration based on tributary area of the diaphragm located at each vertical resisting element.

0306.5.6.3 Horizontal Torsion

For rigid diaphragms, the distribution of lateral forces at each level shall consider the effect of the horizontal torsion. The horizontal torsion consists of the inherent torsional moment, M_t, and the accidental torsional moments, M_{ta}. The inherent torsional moment, M_t, results from the eccentricity between the locations of the center of mass and the center of rigidity. The accidental torsional moment, M_{ta}, is caused by an assumed displacement of the mass each way from its actual location by a distance equal to 5 percent of the dimension of the structure perpendicular to the direction of the applied forces. The accidental eccentricity shall be considered in both orthogonal directions.

0306.5.6.4 Amplification of Torsion

For structures assigned to Seismic Design Category C or D in Section 0306.4.2, where type H-1 torsional irregularity exists as defined in <Table 0306.4.4>, the effects of torsional irregularity shall be accounted for by multiplying the sum of M_t plus M_{ta} at each level by a torsional amplification factor, A_x, determined from following equation:

$$A_x = \left[\frac{\delta_{\max}}{1.2\delta_{avg}} \right]^2 \quad (0306.5.11)$$

where

$\delta_{\max}$: The maximum displacement at level x

δ_{avg} : The average of the displacements at the extreme points of the structure at level x

The torsional amplification factor, A_x, is not required to exceed 3.0. The more severe loading for each element shall be considered for design.

0306.5.6.5 Overturning Moment

The structure shall be designed to resist overturning effects caused by the seismic forces determined in Section 0306.5.

Overturning moment at level x, M_x, shall be determined from following Equation :

$$M_x = \tau \sum_{i=x}^{n} F_i (h_i - h_x) \qquad (0306.5.12)$$

where

F_i : Design lateral force at level i

h_i : The height in meters from the base to level i

h_x : The height in meters from the base to level x

τ : Overturning moment reduction factor determined as follows :

① 1.0 for the top ten stories,

② 0.8 for the 20th story from the top and below, and

③ a value between 1.0 and 0.8 determined by a straight line interpolation for stories between the 20th and 10th stories below the top.

0306.5.7 Story Drift Determination and P-Delta Effects

0306.5.7.1 Story Drift Determination

The design story drift, Δ, shall be computed as the difference of the deflections at the center of mass at the top and bottom of the story under consideration. Where allowable stress design is used, Δ shall be computed using the strength level seismic forces without reduction factor 0.7. For structures assigned to Seismic Design Category C or D having irregularity Type H-1 of <Table 0306.4.4>, the design story drift, Δ, shall be determined as the largest difference of the deflections along any of the edges of the structure at the top and bottom of the story under consideration.

The deflections of level x at the center of the mass, δ_x, shall be determined in accordance with the following equation.

$$\delta_x = \frac{C_d \, \delta_{xe}}{I_E} \qquad (0306.5.13)$$

where

C_d : The deflection amplification factor from <Table 0306.6.1>

δ_{xe} : The deflections determined by an elastic analysis

I_E : The occupancy importance factor from <Table 0306.4.1>

The design story drift, Δ, determined in this section shall not exceed the allowable story drift obtained from <Table 0306.4.7>. For determining compliance with the story drift limits of Section 0306.4.6, it shall be permitted to determine the elastic drifts, δ_{xe}, using seismic design forces based on the computed fundamental period of the structure without the upper limit specified in Section 0306.5.3.

It is permitted to multiply design story drift, Δ, by the amplification factor $a_d = 1.0/(1-\theta)$ for P-delta effects, where θ is the stability coefficient defined as Section 0306.5.7.2

0306.5.7.2 P-Delta Effects

(1) P-delta effects on story shears and moments, the resulting member forces and moments, and the story drifts induced by these effects are not required to be considered when the stability coefficient θ as determined by the following equation is equal to or less than 0.1 :

$$\theta = \frac{P_x \Delta}{V_x h_{sx} C_d} \qquad (0306.5.14)$$

where

P_x : The total vertical design load at and above level x ; when calculating P_x, the individual load factors need not exceed 1.0.

Δ : The design story drift occurring simultaneous with V_x

V_x : The seismic shear force acting between levels x and $x-1$

h_{sx} : The story height below level x

C_d : The deflection amplification factor in <Table 0306.6.1>

(2) The stability coefficient, θ, determined by Equation (0306.5.14) shall not exceed θ_{max}.

Where θ is greater than θ_{max}, the structure is potentially unstable and shall be redesigned.

$$\theta_{max} = \frac{0.5}{\beta C_d} \leqq 0.25 \qquad (0306.5.15)$$

where β is the ratio of shear demand to shear capacity for the story between levels x and $x-1$. This ratio is permitted to be conservatively taken as 1.0.

(3) Where the stability coefficient, θ, is greater than 0.1 but less than or equal to $\theta_{\max}$, the incremental factor related to P-delta effects on displacements and member forces shall be determined by rational analysis. Alternatively, it is permitted to multiply displacements and member forces by the amplification factor $a_d = 1.0/(1-\theta)$.

(4) Where the P-delta effect is included in an automated analysis, Equation (0306.5.15) shall still be satisfied, however, the value of θ computed from Equation (0306.5.14) using the results of the P-delta analysis is permitted to be divided by (1+θ) before checking Equation (0306.5.15).

0306.5.8 Soil Structure Interaction

In the structural analysis, foundation models shall incorporate fixed end supports or foundation stiffnesses computed by established principles of foundation mechanics. Where lateral displacement of the basement is restricted by the adjacent foundation, stiffness of the foundation shall be ignored.

0306.6 SEISMIC FORCE-RESISTING SYSTEM

The appropriate response modifications coefficient, R, system overstrength factor, Ω_0, and the deflection amplification factor, C_d, indicated in <Table 0306.6.1> shall be used in determining the base shear, element design forces, and design story drift.

Seismic force-resisting systems that are not contained in <Table 0306.6.1> shall be permitted if analytical and test data establish the dynamic characteristics and demonstrate the lateral force resistance and energy dissipation capacity to be equivalent to the structural systems listed in <Table 0306.6.1> for equivalent values of response modification coefficient, R, system overstrength factor, Ω_0, and the deflection amplification factor, C_d.

0306.6.1 Dual system

The total seismic force resistance is to be provided by the combination of the moment frames and the shear walls or braced frames in proportion to their rigidities. For a dual system, the moment frames shall be capable of resisting at least 25 percent of the design seismic forces.

〈TABLE 0306.6.1〉 DESIGN COEFFICIENTS AND FACTORS FOR SEISMIC FORCE-RESISTING SYSTEMS

Seismic Force-Resisting System[1]	Design Coefficients and Factors			Structural System Limitations and Building Height(m) Limit		
	Response Modification Coefficient R	System Over strength Factor Ω_0	Deflection Amplification Factor C_d	Seismic Design Category A or B	Seismic Design Category C	Seismic Design Category D
1. Bearing Wall Systems						
1-a. Special reinforced concrete shear walls	5.5	2.5	5.5	-	-	-
1-b. Ordinary reinforced concrete shear walls	4.5	2.5	4	-	-	60
1-c. Reinforced masonry shear walls	2.5	2.5	1.5	-	60	NP
1-d. Unreinforced masonry shear walls	1.5	2.5	1.5	-	NP	NP
2. Building Frame Systems						
2-a. Steel eccentrically braced frames (moment resisting connections at column away from links)	8	2	4	-	-	-
2-b. Steel eccentrically braced frames (non-moment resisting connections at column away from links)	7	2	4	-	-	-
2-c. Special steel concentrically braced frame	6	2	5	-	-	-
2-d. Ordinary steel concentrically braced frame	3.25	2	3.25	-	-	-
2-e. Composite steel and concrete eccen trically braced frames.	8	2	4	-	-	-
2-f. Special composite steel and concrete concentrically braced frames*	5	2	4.5	-	-	-
2-g. Ordianry composite steel and concrete concentrically braced frames*	3	2	3	-	-	-
2-h. Composite steel plate shear walls	6.5	2.5	5.5	-	-	-
2-i. Special composite reinforced concrete shear walls with steel elements	6	2.5	5	-	-	-

<TABLE 0306.6.1> DESIGN COEFFICIENTS AND FACTORS FOR SEISMIC FORCE-RESISTING SYSTEMS(계속)

Seismic Force-Resisting System[1]	Design Coefficients and Factors			Structural System Limitations and Building Height(m) Limit		
	Response Modification Coefficient R	System Over strength Factor Ω_0	Deflection Amplification Factor C_d	Seismic Design Category A or B	Seismic Design Category C	Seismic Design Category D
2-j. Ordinary composite reinforced concrete shear walls with steel elements	5	2.5	4.5	-	-	60
2-k. Special steel plate shear walls	7	2	6	-	-	-
2-l. Buckling-restrained braced frames (moment-resisting beam-column connections)	8	2.5	5	-	-	-
2-m. Buckling-restrained braced frames (non-moment-resisting beam-column connections)	7	2	5.5	-	-	-
2-n. Special reinforced concrete shear walls	6	2.5	5	-	-	-
2-o. Ordinary reinforced concrete shear walls	5	2.5	4.5	-	-	60
2-p. Reinforced masonry shear walls[2]	3	2.5	2	-	60	NP
2-q. Unreinforced masonry shear walls	1.5	2.5	1.5	-	NP	NP
3. Moment-Resisting Frame Systems						
3-a. Special steel moment frames	8	3	5.5	-	-	-
3-b. Intermediate steel moment frames	4.5	3	4	-	-	-
3-c. Ordinary steel moment frames	3.5	3	3	-	-	-
3-d. Special composite moment frames	8	3	5.5	-	-	-
3-e. Intermediate composite moment frames	5	3	4.5	-	-	-
3-f. Ordinary composite moment frames	3	3	2.5	-	-	-
3-g. Composite partially restrained moment frames	6	3	5.5	-	-	-

〈TABLE 0306.6.1〉 DESIGN COEFFICIENTS AND FACTORS FOR SEISMIC FORCE-RESISTING SYSTEMS (CONTINUED)

Seismic Force-Resisting System[1]	Design Coefficients and Factors			Structural System Limitations and Building Height(m) Limit		
	Response Modification Coefficient R	System Over strength Factor Ω_0	Deflection Amplification Factor C_d	Seismic Design Category A or B	Seismic Design Category C	Seismic Design Category D
3-h. Special reinforced concrete moment frames	8	3	5.5	-	-	-
3-i. Intermediate reinforced concrete moment frames	5	3	4.5	-	-	-
3-j. Ordinary reinforced concrete moment frames	3	3	2.5	-	-	NP
4. Dual Systems with Special Moment Frames						
4-a. Steel eccentrically braced frames	8	2.5	4	-	-	-
4-b. Special steel concentrically braced frames	7	2.5	5.5	-	-	-
4-c. Composite steel and concrete eccentrically braced frames	8	2.5	4	-	-	-
4-d. Special composite steel and concrete concentrically braced frames	6	2.5	5	-	-	-
4-e. Composite steel plate shear walls	7.5	2.5	6	-	-	-
4-f. Special composite reinforced concrete shear walls with steel elements	7	2.5	6	-	-	-
4-g. Ordinary composite reinforced concrete shear walls with steel elements	6	2.5	5	-	-	-
4-h. Buckling-restrained braced frames	8	2.5	5	-	-	-
4-i. Special steel plate shear walls	8	2.5	6.5	-	-	-
4-j. Special reinforced concrete shear walls	8	2.5	6.5	-	-	-
4-k. Ordinary reinforced concrete shear walls	7	2.5	6	-	-	-
5. Dual Systems with Intermediate Moment Frames						
5-a. Special steel concentrically braced frames	6	2.5	5	-	-	-
5-b. Special reinforced concrete shear walls	6	2.5	5	-	-	-

〈TABLE 0306.6.1〉 DESIGN COEFFICIENTS AND FACTORS FOR SEISMIC FORCE-RESISTING SYSTEMS (CONTINUED) (계속)

Seismic Force-Resisting System[1]	Design Coefficients and Factors			Structural System Limitations and Building Height(m) Limit		
	Response Modification Coefficient R	System Over strength Factor Ω_0	Deflection Amplification Factor C_d	Seismic Design Category A or B	Seismic Design Category C	Seismic Design Category D
5-c. Ordinary reinforced concrete shear walls	5.5	2.5	4.5	-	-	60
5-d. Special composite steel and concrete concentrically braced frames	5.5	2.5	4.5	-	-	-
5-e. Ordinary composite steel and concrete concentrically braced frames	3.5	2.5	3	-	-	-
5-f. Ordinary composite reinforced concrete shear walls with steel elements	5	3	4.5	-	-	60
5-g. Reinforced masonry shear walls[1]	3	3	2.5	-	60	NP
6. Inverted Pendulum Systems						
6-a. Special steel moment frames	2.5	1.25	2.5	-	-	-
6-b. Intermediate steel moment frames	1.5	1.25	1.5	-	-	-
6-c. Ordinary moment frames	1.25	1.25	1.25	-	-	-
6-d. Special reinforced concrete moment frames	2.5	1.25	2.5	10	10	10
6-e. Intermediate reinforced concrete moment frames	1.5	1.25	1.5	10	10	NP
6-f. Ordinary reinforced concrete moment frames	1.25	1.25	1.25	10	NP	NP
7. Shear wall-frame interactive system with ordinary reinforced concrete moment frames and ordinary reinforced concrete shear walls	4.5	2.25	4	-	-	60
8. Steel Systems Not Specifically Detailed for Seismic Resistance	3	3	3	-		60

1) Details on each system are determined by the corresponding design code or analytical and experimental results performed by authorized research facilities.

0306.6.2 Combinations of Framing Systems in the Same Direction

For other than dual systems, where a combination of different lateral force-resisting systems is utilized to resist lateral forces in the same direction, the value of the response modification coefficient, R, used in that direction shall not be greater than the least value of any of the systems utilized in the same direction.

0306.6.3 Combinations of Framing Systems

Different seismic force-resisting systems are permitted to be used to resist seismic forces along the two orthogonal axes of the structure. Where different systems are used, the respective R, Ω_0, and C_d coefficients shall apply to each system, including the limitations on the systems used contained in <Table 0306.6.1>.

0306.6.3.1 R and Ω_0 Values for Vertical Combination

The value of the response modification coefficient, R, used for design at any story shall not exceed the lowest value of R that is used in the same direction at any story above that story except roof story. The system overstrength factor, Ω_0, used for the design at any story shall not be less than the largest value of this factor that is used in the same direction at any story above that story.

Exceptions :

(1) Detached one- and two-family dwellings of light-frame construction.

(2) For structures with a weight equal to or less than 10 percent of the weight of the structure, response modification coefficient R and system overstrength Ω_0 can be determined independently from the overall building.

(3) A two-stage equivalent lateral force procedure is permitted to be used for structures having a flexible upper portion above a rigid lower portion, provided that the design of the structure complies with the following:

① The stiffness of the lower portion must be at least 10 times the stiffness of the upper portion.

② The period of the entire structure shall not be greater than 1.1 times the period of the upper portion considered as a separate structure fixed at the base.

③ The flexible upper portion shall be designed as a separate structure using the appropriate value of R.

④ The rigid lower portion shall be designed as a separate structure using the appropriate values of R. The reactions from the upper portion shall be those determined from the analysis of the upper portion amplified by the ratio of the R of the upper portion over R of the lower. This ratio shall not be less than 1.0.

0306.6.3.2 Combination Framing Detailing Requirements

Structural components common to different framing systems used to resist seismic motions shall be designed using the details required by the highest response modification coefficient, R.

0306.6.4 Structural System Limitations for Seismic Design Category D

Structures assigned to Seismic Design Category D shall comply with the structural system limitations in <Table 0306.6.1> and the followings.

0306.6.4.1 Interaction Effects

Moment-resisting frames that are enclosed or adjoined by more rigid elements not considered to be part of the seismic force-resisting system shall be designed so that the action or failure of those elements will not impair the vertical load and seismic force resisting capability of the frame. The design shall consider the effect of these rigid elements on the structural system at structural deformations corresponding to the design story drift, Δ, as determined in Section 0306.5.7.1. In addition, the effects of these elements shall be considered where determining whether a structure has one or more of the irregularities defined in Section 0306.4.4.

0306.6.4.2 Deformation Compatibility

Every structural component not included in the seismic force-resisting system in the direction under consideration shall be designed to be adequate for the vertical load-carrying capacity and the induced moments and shears resulting from the design story drift, Δ, as determined in accordance with Section 0306.5.7.1. Where allowable stress design is used, the design story drift, Δ, shall not be multiplied by load factor 0.7. When determining the moments and shears induced in components that are not included in the seismic force-resisting system in the direction under consideration, the stiffening effects of adjoining rigid structural and nonstructural elements shall be considered.

0306.6.4.3 Building Height Limits

The height limit in <Table 0306.6.1> shall be applied to buildings assigned to Seismic Design Category D.

0306.7 DYNAMIC ANALYSIS

0306.7.1 Selection of Analysis Method

The following dynamic analysis procedures may be performed in accordance with the requirements of this section :

(1) Response Spectrum Analysis

(2) Linear Time History Analysis.

(3) Nonlinear Time History Analysis.

0306.7.2 Modeling

A mathematical model of the building shall be constructed that represents the spatial distribution of mass and stiffness throughout the structure. For regular structures with independent orthogonal seismic-force resisting systems, independent two-dimensional models are permitted to be constructed to represent each system. For irregular structures or structures without independent orthogonal systems, a three-dimensional model incorporating a minimum of three dynamic degrees of freedom consisting of translation in two orthogonal plan directions and torsional rotation about the vertical axis shall be included at each level of the structure. Where the diaphragms are not rigid compared to the vertical elements of the lateral-force-resisting system, the model should include representation of the diaphragm's flexibility and such additional dynamic degrees of freedom required to account for the participation of the diaphragm in the structure's dynamic response. Stiffness properties of concrete and masonry elements shall include the effects of cracked sections. For steel moment frame systems, the contribution of panel zone deformations to overall story drift shall be included. In case $P-\Delta$ effects are considered to be significant, the effects shall be included in the analysis modeling. When the area of the basement is significantly larger than that of the super-structure, the super-structure can be analyzed separately from the basement structure. Otherwise, the basement shall be modeled in conjunction with the super-structure. In this case the stiffness of the soil adjacent to the basement shall be neglected.

0306.7.3 Response Spectrum Analysis

0306.7.3.1 Modal Characteristics

The modal vibration characteristics such as the period of each mode, the modal shape vector, the modal participation factor, and the modal mass shall be computed by established methods of structural analysis for the fixed-base condition using the masses and elastic stiffnesses of the seismic force-resisting system. The analysis shall include a sufficient number of modes to obtain a combined modal mass participation of at least 90% of the actual mass in each of two orthogonal directions.

0306.7.3.2 Modal Base Shear

The portion of the base shear contributed by the mth mode, V_m, shall be determined from

the following equations :

$$V_m = C_{sm} \overline{W_m} \quad (0306.7.1)$$

$$\overline{W_m} = \frac{\left(\sum_{i=1}^{n} w_i \Phi_{im}\right)^2}{\sum_{i=1}^{n} w_i \Phi_{im}^2} \qquad (0306.7.2)$$

where

C_{sm} : The modal seismic response coefficient determined in Equation (0306.7.3)

$\overline{W_m}$: effective modal gravity load.

w_i : The portion of the total gravity load, W, of the building at level i, where W=the total dead load and other loads listed below :

① In areas used for storage, a minimum of 25 percent of the floor live load. (Floor live load in public garages and open parking structures need not be included.)

② Where an allowance for partition load is included in the floor load design, the actual partition weight or a minimum weight of 0.5 kN/㎡ of floor area, whichever is greater.

③ Total operating weight of permanent equipment.

④ Twenty percent of flat roof snow load where the flat roof snow load exceeds 1.5 kN/㎡.

ϕ_{im} : i th component of the mth modal vector

The modal seismic response coefficient, C_{sm}, shall be determined by the following equation :

$$C_{sm} = \frac{S_{am}}{\left(\frac{R}{I_E}\right)} \qquad (0306.7.3)$$

where

I_E : The occupancy importance factor determined in accordance with <Table 0306.4.1>.

S_{am} : The modal design spectral response acceleration at period T_m determined from either the general design response spectrum or a site-specific response spectrum

R : The response modification factor determined from <Table 0306.6.1>.

For buildings on site S_D and S_E, the modal seismic design coefficient, C_{sm}, for modes other than the fundamental mode that have periods less than 0.3 second is permitted to be determined by the following equation :

$$C_{sm} = \frac{S_{DS}}{2.5\left(\frac{R}{I_E}\right)}(1.0 + 5.0\,T_m) \qquad (0306.7.4)$$

where

I_E : The occupancy importance factor determined in accordance with <Table 0306.4.1>.

R : The response modification factor determined from <Table 0306.6.1>

S_{DS} : The design spectral response acceleration at short periods as defined in <Table 0306.3.3>

T_m : The modal period of vibration, in seconds, of the mth mode

0306.7.3.3 Modal Forces, Deflections, and Drifts

The modal force, F_{xm}, at each level shall be determined by the following equations :

$$F_{xm} = C_{vxm}\,V_m \qquad (0306.7.5)$$

$$C_{vxm} = \frac{w_x\,\phi_{xm}}{\sum_{i=1}^{n} w_i\,\phi_{im}} \qquad (0306.7.6)$$

where

C_{vxm} : The vertical distribution factor in the mth mode

V_m : total design lateral force or shear at the base in the mth mode obtained by Equation (0306.7.1)

w_i , w_x : Effective weight of the ith and the xth story

ϕ_{im} : The ith component of the mth mode vector

ϕ_{xm} : The xth component of the mth mode vector

The modal deflection at each level, δ_{xm}, shall be determined by the following equation :

$$\delta_{xm} = \frac{C_d \, \delta_{xem}}{I_E} \tag{0306.7.7}$$

where

- C_d : The deflection amplification factor determined from <Table 0306.6.1>
- I_E : The occupancy importance factor determined in accordance with <Table 0306.4.1>
- δ_{xem} : The deflection of level x in the mth mode at the center of the mass at level x determined by an elastic analysis.

The elastic deflection, δ_{xem}, can also be determined by the following equation:

$$\delta_{xem} = \left(\frac{g}{4\pi^2}\right)\left(\frac{T_m^2 \; F_{xm}}{w_x}\right) \tag{0306.7.8}$$

where

- F_{xm} : The seismic story force of the level x corresponding to the mth mode
- g : The acceleration due to gravity
- T_m : The modal period of vibration, in seconds, of the mth mode
- w_x : The effective weight of the level x

The modal drift in a story, Δ_m, shall be computed as the difference of the deflections, δ_{xm}, at the top and bottom of the story under consideration.

0306.7.3.4 Modal Story Shears, Moments, and Member Forces

The story shears, story overturning moments, and the member forces due to the seismic forces determined from Section 0306.7.3.3 shall be computed for each mode by linear static methods.

0306.7.3.5 Design values

(1) The design value for the modal base shear, V_t, story shear, story

drift, deflection, member forces shall be determined by taking the square root of the sum of the squares, SRSS, of each of the modal values or by the complete quadratic combination, CQC, technique.

(2) When the base shear, V_t, obtained using the response spectrum analysis procedure is less than 85% of the base shear V obtained by the equivalent lateral force procedure presented in Section 0306.5.3, the design values obtained in Section 0306.7.3.5(1) shall be multiplied by the modification factor, C_m, defined as follows :

$$C_m = 0.85\frac{V}{V_t} \geq 1.0 \qquad (0306.7.9)$$

The modification factor, C_m, shall not be multiplied to inter-story drift.

0306.7.3.6 Lateral Drift and P-Delta Effects

The inelastic lateral drift and P-delta effects shall be determined in accordance with Section 0306.5.7. When P-delta effects are included in the analysis, P-delta effects need not be considered additionally.

0306.7.4 TIME HISTORY ANALYSIS

0306.7.4.1 Determination of Time History

Time history analysis shall be performed with not less than three recorded events. In three-dimensional analysis, each recorded event shall be composed of a pair of ground motions perpendicular to each other in a plane. Where the required number of recorded ground motion pairs are not available, appropriate simulated ground motion pairs shall be used to make up the total number required. For each pair of horizontal ground motion components, an SRSS spectrum shall be constructed by taking the square root of the sum of the squares of the 5 percent damped response spectra for the components. Each pair of motions shall be scaled such that the average value of the SRSS spectra from all horizontal component pairs does not fall below 1.3 times the design spectrum for periods ranging from 0.2T second to 1.5T seconds, where T is the natural period of the fundamental mode of the structure, by more than 10%. When the ground motion pairs need to be scaled, the same scale factor shall be applied to the two perpendicular components. If three time history analyses are performed, then the maximum response of the parameter of interest shall be used for design. If seven or more time history analyses are performed, then the average value of the response parameter of interest may be used for design. In two-dimensional analysis, the ground motions shall be scaled such that the average value of the 5% damped response spectra for the suite of motions is not less than design response spectrum for the site for periods ranging from 0.2T to 1.5T seconds, where T is the natural period of the structure in the fundamental mode for the direction of response being analyzed.

0306.7.4.2 Linear Time History analysis

The design values such as story shear, story overturning moment, and member forces shall be obtained by the linear time history analysis results multiplied by the importance factor and divided by the response modification factor. The design values shall be scaled in accordance with Section 0306.7.3.5.

0306.7.4.3 Nonlinear Time History analysis

A mathematical model of the structure shall be constructed that represents the nonlinear capacity and characteristics of a structural member, considering the importance factor, consistent with suitable experiment data or analyses. The responses shall not be divided by R/I_E. The maximum nonlinear drifts shall conform to Section 0306.4.6.

0306.7.4.4 Consideration of Soil Effect

For direct consideration of earthquake ground motion, the soil adjacent to the structure can be included in the structural analysis. In this case large area of soil located above the bed rock shall be modeled so that the ground motion of the soil located far away from the structure is not affected by the soil-structure interaction. Analysis shall be carried out using the bed rock motion which has the characteristics of the bed rock.

0306.8 DESIGN AND DETAILING REQUIREMENTS

The design and detailing of the components of the seismic force -resisting system, except for the structures assigned to Seismic Design Category A, shall comply with the requirements of this section.

0306.8.1 Discontinuities in Vertical System

Structures with a discontinuity in lateral capacity, vertical irregularity Type V-5 as defined in <Table 0306.4.5>, shall not be more than two stories or 9m in height where the weak story has a calculated strength of less than 65 percent of the story above. Where the weak story is capable of resisting a total seismic force equal to the design seismic load multiplied by the system overstrength factor, Ω_0, the height limitation does not apply.

0306.8.2 Inverted Pendulum-Type Structures

Supporting columns of inverted pendulum-type structures shall be designed for the bending moment calculated at the base determined using the procedures given in Section 0306.5 and varying uniformly to a moment at the top equal to one-half the calculated bending moment at the base.

0306.8.3 Elements Supporting Discontinuous Walls or Frames

Columns or other elements supporting discontinuous walls or frames of structures having plan irregularity of Type H-4 of <Table 0306.4.4> or vertical irregularity of Type V-4 of <Table 0306.4.5> shall be designed for the special seismic load combinations of Section 0306.2.

0306.8.4 Direction of Seismic Load

0306.8.4.1 Seismic Design Category B

The directions of application of seismic forces used in the design shall be those that will produce the most critical load effects in each component. This requirement is assume to be satisfied if the design seismic forces are applied independently in any of two orthogonal directions.

0306.8.4.2 Seismic Design Category C

Loading applied to structures assigned to this Category shall, as a minimum, conform to the requirements of Section 0306.8.4.1. The seismic design loads of the structures that have plan irregularity Type H-5 of <Table 0306.4.4> shall be obtained by either of the following methods :

(1) One hundred percent of the forces for one direction plus 30% of the forces for the perpendicular direction. Select larger of the two possible combinations.

(2) The effects of the two orthogonal directions are combined on a square root of the sum of the square, SRSS, basis.

0306.8.4.3 Seismic Design Category D

The seismic design loads of the structures shall be obtained by either of the following methods:

(1) One hundred percent of the forces for one direction plus 30% of the forces for the perpendicular direction. Select larger of the two possible combinations.

(2) The effects of the two orthogonal directions are combined on a square root of the sum of the square, SRSS, basis.

0306.8.5 Vertical Seismic Forces

Horizontal cantilevers and horizontal prestressed components assigned to Seismic Design Category D shall be designed to resist a minimum net upward force of 0.2 times the dead load in addition to applicable load combinations.

0306.8.6 Building Separations

Structures assigned to Seismic Design Category D shall be separated from adjoining structures. Adjacent buildings on the same property shall be separated by at least δ_{MT} :

$$\delta_{MT} = \sqrt{(\delta_{M1})^2 + (\delta_{M2})^2} \qquad (0306.8.1)$$

where δ_{M1} and δ_{M2} are the displacements of the adjacent buildings computed in accordance with Section 0306.5.7 or 0306.7.4. A structure adjoining a property line shall be set back from the property line at least δ_M of the structure.

0306.9 ARCHITECTURAL, MECHANICAL AND ELECTRICAL COMPONENTS

0306.9.1 General

Architectural, mechanical, electrical, and other nonstructural components in buildings shall be designed and constructed to resist the equivalent static forces and displacements determined in accordance with this section. Where the combined weight of the supported components and nonbuilding structures exceeds 25 percent of the weight of the structures, structures shall be designed in accordance with Section 0306.10.

0306.9.1.1 Applicability to Components

Components shall be considered to have the same Seismic Design Category as that of the structure that they occupy or to which they are attached, as described in Section 0306.4.3. The following nonstructural components are exempt from the requirements of this section.

(1) Components in Seismic Design Category A.

(2) Other than parapets supported by bearing walls or shear walls, architectural components in Seismic Design Category B when the component importance factor, I_p, is equal to 1.0.

(3) Mechanical and electrical components in Seismic Design Category B.

(4) Mechanical and electrical components in Seismic Design Category C, provided that the component importance factor, I_p, is equal to 1.0

(5) Mechanical and electrical components in all Seismic Design Categories that are linked with ductwork or piping by flexible connections, mounted at 1.2 meters or less above a floor level, and weigh 1,800 N or less, provided that the component importance factor, I_p, is equal to 1.0.

(6) Mechanical and electrical components in Seismic Design Category D

that are linked with ductwork or piping by flexible connections and weigh 100 N or less, provided that the component importance factor, I_p, is equal to 1.0.

0306.9.1.2 Equivalent Seismic Forces

Equivalent seismic forces, F_p, shall be determined in accordance with Equation (0306.9.1). The force F_p shall be applied independently longitudinally and laterally in combination with service loads associated with the component. When positive and negative wind loads exceed F_p for nonbearing exterior wall, these wind loads shall govern the design.

$$F_p = \frac{0.4\, a_p\, S_{DS}\, W_p}{\left(\frac{R_p}{I_p}\right)} \left(1 + 2\frac{z}{h}\right) \qquad (0306.9.1)$$

F_p is non required to be taken as greater than

$$F_p = 1.6\, S_{DS}\, I_p\, W_p \qquad (0306.9.2)$$

and F_p shall not be taken as less than

$$F_p = 0.3\, S_{DS}\, I_p\, W_p \qquad (0306.9.3)$$

where

a_p : component amplification factor that varies from 1.0 to 2.5 (select appropriate value from <Table 0306.9.1> or <Table 0306.9.2>)

F_p : seismic design force centered applied at the component's center of gravity and distributed relative to component's mass distribution

I_p : component importance factor that is either 1.0 or 1.5, as determined in Section 0306.9.1.4

h : averaged roof height of structure with relative to the base elevation

R_p : component response modification factor that varies from 1.0 to 5.0 (select appropriate value from <Table 0306.9.1> or <Table 0306.9.2>)

S_{DS} : design spectral response acceleration at short period as determined in Section 0306.3.3

W_p : omponent operating weight

z : height in structure of point of attachment of component.

$z = 0$: for items at or below the base

$z = h$: for items at or above the roof

0306.9.1.3 Seismic Relative Displacements

Seismic relative displacements, D_p, shall be determined in accordance with the equations in this section. For two connection points on the same Structure A or the same structural system, one at a level x and the other at a level y, D_p shall be determined as

$$D_p = \delta_{xA} - \delta_{yA} \tag{0306.9.4}$$

D_p is not required to be taken as greater than

$$D_p = (X - Y)\frac{\Delta_{aA}}{h_{sx}} \tag{0306.9.5}$$

For two connection points on separate Structure A and B or separate structural system, one at a level x and the other at a level y, D_p shall be determined as

$$D_p = |\delta_{xA}| - |\delta_{yB}| \tag{0306.9.6}$$

D_p is not required to be taken as greater than

$$Dp = \frac{X\Delta_{aA}}{h_{sx}} + \frac{Y\Delta_{aB}}{h_{sx}} \tag{0306.9.7}$$

where

D_p : relative seismic displacement that the component must be designed to accommodate

h_{sx} : story height used in the definition of the allowable drift in <Table 0306.4.7>.

δ_{xA}, δ_{yA}, δ_{yB} : deflection at building level x or y of Structure A or B, determined by an elastic analysis as defined in

Sections from 0306.5.3 to 0306.5.7

X : height of upper support attachment at level x as measured from the base

Y : height of lower support attachment st level x as measured from the base

Δ_{aA}, Δ_{aB} : allowable story drift for Structure A or B as defined in <Table 0306.4.7>

0306.9.1.4 Component Importance Factor

The component importance factor, I_p, for other components shall be taken as 1.0, but the factor shall be taken as 1.5 if any of the following conditions apply:

(1) Life-safety component is required to function after an earthquake.

(2) Component contains hazardous or flammable materials.

(3) Storage racks in occupancies open to the general public
(eg. warehouse retail stores)

(4) Component is in or attached to an Occupancy Category S structure in <Table 0306.4.1> and it is needed for continued operation of the facility or it is its failure could impair the continued operation of the facility.

0306.9.1.5 Component Anchorage

Components shall be anchored in accordance with the following:

(1) The force in the connected part shall be determined based on the prescribed forces for the component specified in Section 0306.9.1.2. Where the component anchorage is provided by shallow expansion anchors, shallow chemical anchors, or shallow (low ductility) cast-in-place anchor, a value of $R_p = 1.5$ shall be used to determine the forces on the connected part.

(2) Anchors embedded in concrete or masonry shall be proportioned to carry the lesser of the following :

① the design strength of connected part

② 1.3 times the force in the connected part as given by $F_p \times R_p$

③ The maximum force that can be transferred to the connected part by the component structural system

(3) Determination of forces in anchors shall include the expected conditions of installation including eccentricities and prying effects.

0306.9.2 Architectural Component Design

Architectural systems, components or elements listed in <Table 0306.9.1> and their attachments shall meet the requirements of Section 0306.9.1

0306.9.3 Mechanical and Electrical Component Design

Attachments and equipment supports for the mechanical and electrical systems, components or elements shall meet the requirements of Section 0306.9.1.

〈TABLE 0306.9.1〉 COEFFICIENTS FOR ARCHITECTURAL COMPONENT

Architectural Component or Element	a_p [1)]	R_p
1. Interior Nonstructural Walls and Partitions		
a. Plain (unreinforced) masonry walls	1.0	1.25
b. All other walls and partitions	1.0	2.5
2. Cantilever Elements (Unbraced or braced to structural frame below its center of mass)		
a. Parapets and cantilever interior nonstructural walls	2.5	2.5
b. Chimneys and stacks when laterally braced or supported by structural frame	2.5	2.5
3. Cantilever Elements (Braced to structural frame above its center of mass)		
a. Parapets	1.0	2.5
b. Chimneys and Stacks	1.0	2.5
c. Exterior Nonstructural Walls	1.0	2.5
4. Exterior Nonstructural Wall Elements and Connections		
a. Wall Element	1.0	2.5
b. Body of wall panel connections	1.0	2.5
c. Fasteners of the connecting system	1.25	1.0

〈TABLE 0306.9.1〉 COEFFICIENTS FOR ARCHITECTURAL COMPONENT (계속)

Architectural Component or Element	a_p [1)]	R_p
5. Veneer		
a. Limited deformability elements and attachments	1.0	2.5
b. Low deformability elements and attachments	1.0	1.25
6. Penthouse (except when framed by an extension of the building frame)	2.5	3.5
7. Ceilings	1.0	2.5
8. Cabinets		
a. Storage cabinets and laboratory equipment	1.0	2.5
9. Access Floors		
a. Special access floors	1.0	2.5
b. All other	1.0	1.25
10. Appendages and Ornamentations	2.5	2.5
11. Signs and Billboards	2.5	2.5
12. Other Rigid Components		
a. High deformability elements and attachments	1.0	3.5
b. Limited deformability elements and attachments	1.0	2.5
c. Low deformability elements and attachments	1.0	1.25
13. Other Flexible Components		
a. High deformability elements and attachments	1.0	3.5
b. Limited deformability elements and attachments	2.5	2.5
c. Low deformability elements and attachments	2.5	1.25

1) Where justified by detailed dynamic analyses, a lower value for a_p is permitted, but shall not be less than 1. The reduced value of a_p shall be between 2.5, assigned to flexible or flexibly attached equipment, and 1, assigned to rigid or rigidly attached equipment.

〈TABLE 0306.9.2〉 COEFFICIENTS FOR MECHANICAL AND ELECTRICAL COMPONENT

Mechanical and Electrical Component or Element	a_p	R_p
1. General Mechanical		
a. Boilers and furnaces	1.0	2.5
b. Pressure vessels on skirts and free-standing	2.5	2.5
c. Stacks	2.5	2.5
d. Cantilevered chimneys	2.5	2.5
e. Other	1.0	2.5
2. Manufacturing and Process Machinery		
a. General	1.0	2.5
b. Conveyors (nonpersonnel)	2.5	2.5
3. Piping Systems		
a. High-deformability elements and attachments	1.0	3.5
b. Limited-deformability elements and attachments	1.0	2.5
c. Low-deformability elements and attachments	1.0	1.25
4. HVAC System Equipment		
a. Vibration isolated	2.5	2.5
b. Nonvibration isolated	1.0	2.5
c. Mounted in-line with ductwork	1.0	2.5
d. Other	1.0	2.5
5. Elevator Components	1.0	2.5
6. Escalator Components	1.0	2.5
7. Trussed Towers (free-standing or guyed)	2.5	2.5
8. General Electrical		
a. Distributed Systems (Bus Ducts, Conduit, Cable Tray)	1.0	3.5
b. Equipments	1.0	2.5
9. Lighting Fixtures	1.0	1.25

0306.10 SEISMIC DESIGN REQUIREMENTS FOR NONBUILDING STRUCTURES

0306.10.1 General

0306.10.1.1 Nonbuilding Structures

The requirements of this section apply to self-supporting structures that carry gravity loads that are not defined as buildings, vehicular or railroad bridges, nuclear power generation plants, offshore platforms, or dams.

0306.10.1.2 Nonbuilding Structures Supported by Other Structures

(1) If a nonbuilding structure is supported above the base by another structure and the weight of the nonbuilding structure is less than 25 percent of the combined weight of the nonbuilding structure and the supporting structure, the design seismic forces of the supported nonbuilding structure shall be determined in accordance with the requirements of Section 0306.9.

(2) If the weight of a nonbuilding structure is 25 percent or more of the combined weight of the nonbuilding structure and the supporting structure, the design seismic forces of the nonbuilding structure shall be determined based on the combined nonbuilding structure and supporting structural system.

(3) Response modification factors shall be determined in accordance with following:

① For supported nonbuilding structures that have component dynamic characteristics that are not rigid, the combined system R factor shall be a maximum of 3.

② For supported nonbuilding structures that have rigid component dynamic characteristics, the combined system R factor shall be the value of the supporting structural system.

0306.10.1.3 Architectural, Mechanical, and Electrical Components

Architectural, mechanical, and electrical components supported by nonbuilding structures shall be designed in accordance with Section 0306.9.

0306.10.2 Structural Design Requirements

Design of nonbuilding structures to resist seismic loads shall conform to this section.

0306.10.2.1 Weight

For purpose of calculating design seismic force in nonbuilding structures, the weight shall include dead load and normal operating contents for items such as tanks, vessels, bins, and contents of piping. The weight shall include snow and ice loads when these loads constitute 25 percent or more of the seismic effective weight.

0306.10.2.2 Fundamental Period

The fundamental period of nonbuilding structure shall be determined by appropriate methods which consider deformational and structural characteristics of resisting elements, such as the method described in Section 0306.7.3.1, or estimated by Rayleigh's method.

0306.10.2.3 Drift Limits

The drift limitation of Section 0306.4.6 need not apply to nonbuilding structures if a rational analysis indicates they can be exceeded without adversely affecting structural stability.

0306.10.2.4 Seismic Design Forces

Nonbuilding structures shall be designed to resist minimum seismic lateral forces not less than the requirements of Section 0306.5.1 and following :

(1) The response modification coefficients shall be the lesser of the values given in <Table 0306.10.1> or the values in <Table 0306.6.1>.

(2) For nonbuilding systems with response modification coefficients provided in <Table 0306.10.1>, the minimum value specified in Equation (0306.5.4) shall be replaced by the following :

$$C_S = 0.14\, S_{DS}\, I_E \qquad (0306.10.1)$$

(3) The importance factor shall be given in <Table 0306.10.2>.

The vertical distribution of lateral seismic forces in nonbuilding structures covered by this section shall be determined in accordance with Section 0306.5.5.

0306.10.2.5 Rigid Nonbuilding Structures

Nonbuilding structures that have a fundamental period, T, less than 0.06 second, including their anchorages, shall be designed for the lateral force obtained from the following :

$$V = 0.3\, S_{DS}\, W\, I_E \qquad (0306.10.2)$$

where

I_E : the importance factor as defined in <Table 0306.10.2>

S_{DS} : the site design response acceleration as determined from Section 0306.3.3

V : the total design lateral seismic base shear force applied to a nonbuilding structure

W : nonbuilding structure operating weight as defined in Section 0306.10.2.1

The force shall be distributed with height in accordance with Section 0306.5.5.

〈TABLE 0306.10.1〉 SEISMIC COEFFICIENTS FOR NONBUILDING STRUCTURES

Nonbuilding Structure Type	R	Ω_0	C_d
1. Nonbuilding frame systems			
a. Steel concentric braced frames	5	2	4.5
2. Moment resisting frame systems	4	3	3.5
a. Steel moment frames	5	3	3.5
b. Intermediate reinforced concrete moment frames			
c. Ordinary reinforced concrete moment frames	3	3	2.5
3. Steel storage racks	4	2	3.5
4. Elevated tanks, vessels, bins, or hoppers[1)]			
a. On braced legs	3	2	2.5
b. On unbraced legs	3	2	2.5
c. Single pedestal or skirt supported	2	2	2
d. Welded steel	2	2	2
e. Concrete	2	2	2
5. Horizontal, saddle supported welded steel vessels	3	3	2.5
6. Tanks or vessels supported on structural towers similar to buildings	3	2	2
7. Flat bottom, ground-supported tanks, or vessels			
a. Mechanically anchored (welded or bolted steel)	3	2	2.5
b. Self-anchored (welded or bolted steel)	2.5	2	2

〈TABLE 0306.10.1〉 SEISMIC COEFFICIENTS FOR NONBUILDING STRUCTURES (계속)

Nonbuilding Structure Type	R	Ω_0	C_d
8. Reinforced or prestressed concrete			
a. Tanks with reinforced nonsliding base	2	2	2
b. Tanks with anchored flexible base	3	2	2
9. Tanks with unanchored or unconstrained tanks			
a. Flexible base	1.5	1.5	1.5
b. Other material	1.5	1.5	1.5
10. Cast-in-place concrete silos, stacks, and chimneys having walls continuous to the foundation	3	1.75	3
11. Other reinforced masonry structures not similar to buildings[3]	3	2	2.5
12. Other nonreinforced masonry structures not similar to buildings[3]	1.25	2	1.5
13. Other steel and reinforced concrete distributed mass cantilever structures not covered herein including stacks, chimneys, silos, and skirt-supported vertical vessels that are not similar to buildings	3	2	2.5
14. Trussed tower (freestanding or guyed), guyed stacks and chimneys	3	2	2.5
15. Cooling towers			
a. Concrete or steel	3.5	1.75	3
b. Wood frame	3.5	3	3
16. Telecommunication towers			
a. Truss : Steel	3	1.5	3
b. Pole : Steel	1.5	1.5	1.5
Wood	1.5	1.5	1.5
Concrete	1.5	1.5	1.5
c. Frame : Steel	3	1.5	1.5
Wood	2.5	1.5	1.5
Concrete	2	1.5	1.5
17. Amusement structure and monuments	2	2	2
18. Inverted pendulum-type structures (not elevated tanks)[2]	2	2	2
19. Sign and billboards	3.5	1.75	3
20. Other self-supporting structures, tank, or vessels not covered above	1.25	2	2.5

1) Tower with irregularity as defined in Section 0306.4.4
2) Support for lighting, spot lighting, etc.
3) Masonry structures shall not be allowed in Seismic Design Categories C and D.

〈TABLE 0306.10.2〉 IMPORTANCE FACTOR (IE) AND SEISMIC USE GROUP CLASSIFICATION FOR NONBUILDING STRUCTURE

Importance Factor	I_E = 1.0	I_E = 1.5
Seismic Use Group as Defined in 〈Table 0306.4.1〉	II	S
Hazard	H-1	H-2
Function	F-1	F-2

H-1 = The stored product is biologically or environmentally benign; low fire or low physical hazard.

H-2 = The stored product is rated high or moderate expansion hazard, high fire hazard, or high physical hazard as determined by the authority having jurisdiction.

F-1 = Nonbuilding structures not classified as F-2

F-2 = Seismic Use Group S nonbuilding structure or designated ancillary nonbuilding structures (such as : communication towers, fuel storage tanks, cooling towers, or electrical substation structures required for operation of Seismic Use Group S Structures.)