Japan

Earthquake Resistant Design Method for Buildings

2019

Ministry of Land, Infrastructure, Transport and Tourism

Editorial note: This is a part of tentative English version of a technical guideline about the Earthquake Resistant Design Method.

A Comment on Structural Design Method

a. Format:

☐ Working Stress Design : Allowable Stress ≧ Actual Stress

☑ Ultimate Strength Design: Ultimate Member Strength ≧ Required Member Strength

☑ Limit State Design : Ultimate Lateral Strength ≧ Required Lateral Strength

☐ Other Design Method :

(comment)

The two-phase design procedures are used for moderate and severe earthquake motions. The working stress design procedure is used for gravity loading design and for earthquake resistant design against moderate earthquake motions, while the limit analysis design procedure is used to ensure the minimum resistance against severe earthquake motions.

b. Material Strength (Concrete and Steel):

The working stress for design of gravity loading should be limited to the allowable stress of concrete which is 1/3 of the design concrete strength, and that of steel to be approximately 2/3 of the design yield strength. On the other hand, the working stress for design of earthquake loading should be limited to the allowable stress of concrete which is 2/3 of the design concrete strength, and that of steel to be the yield strength.

The ultimate strength of members is used in the limit analysis procedure to evaluate the ultimate lateral load resistance of buildings.

c. Strength Reduction Factors:

No strength reduction factors are used in design.

d. Load Factors for Gravity Loadings and Load Combination:

Some load factors are used according to the load conditions.

e. Typical Live Load Values:

Office Buildings : 1.8 kN/m^2 (for structural calculations of beam, column and foundation)

Residential Buildings: 1.3 kN/m^2 (for structural calculations of beam, column and foundation)

f. Special Aspects of Structural Design Method

In case that your code is performance-based, please describe the fundamental seismic performance requirement.

Chapter 5: Loads and External Forces
5.5 Seismic Force

Article 88 of the Enforcement Order

(Seismic Force)

Article 88. The seismic force shall be determined by multiplying the total of dead load and live load at each part (snow load in addition in heavy snow areas designated by the Designated Administrative Agency under the proviso to Article 86, paragraph (2)) by the seismic story shear coefficient at the height of each part. The seismic story shear coefficient shall be calculated by the following formula.

$$C_i = Z\, R_t\, A_i\, C_o$$

where,

C_i : Seismic story shear coefficient of the aboveground part of a building at a given height

Z : A value to be specified by the Minister of Land, Infrastructure, Transport and Tourism (the Minister) within a range between 1.0 and 0.7 according to the extent of earthquake damage, seismic activity and other seismic characteristics based on the record of earthquakes in the region concerned

R_t : A value representing vibration characteristics of buildings to be obtained by the calculation method specified by the Minister according to the natural periods in the elastic range of buildings and kinds of soil

A_i: A value representing a vertical distribution of seismic story shear coefficients in i-th story according to the vibration characteristics of buildings to be obtained by the calculation method specified by the Minister

C_o : Standard shear coefficient

(2) The standard shear coefficient shall be 0.2 or more. Provided, that the value shall be 0.3 or more for wooden buildings (excluding those which conform to the standards as mentioned in Article 46, paragraph (2), item (i)) within the areas designated by the Designated Administrative Agency by regulations as areas where the ground is extremely soft, based upon the standards established by the Minister.

(3) In calculating a required value of retained horizontal strength under Article 82-3, item (ii), the standard shear coefficient, notwithstanding the provisions of the preceding paragraph, shall be 1.0 or more.

(4) The seismic force acting upon each underground part of a building shall be calculated by multiplying the total of dead load and live load at each part by seismic coefficient which satisfies the following formula. Provided, that other calculation methods of seismic force may be employed if calculation of seismic force is possible therewith based on proper analyses of vibration characteristics of the building at the time of an earthquake.

$$k \geq 0.1\left(1 - \frac{H}{40}\right) Z$$

where,

k : Seismic coefficient

H : Depth, in meters, of each part of a building below the ground level (to be regarded as 20 in excess thereof)

Z : A value of Z as specified in paragraph (1)

1) Seismic Force Settings

(1) Article 88, paragraph (1) of the Enforcement Order (E.O.) stipulates the method used to calculate seismic force for the above-ground portion of a building. It states that seismic force at a particular height (floor) in a building shall be calculated by multiplying the sum of dead loads and live loads on all parts (snow loads in addition in heavy snow areas) supported by (above) that part of the building by the seismic shear force coefficient ($\boldsymbol{C_i}$) at i-th story. The values of $\boldsymbol{Z}$, $\boldsymbol{R_t}$ and $\boldsymbol{A_i}$ referred to in this paragraph is to be specified by the Minister. The value of $\boldsymbol{C_0}$ is defined in paragraphs (2) and (3) of Article 88.

Because this regulation defines seismic force in terms of story shear force, seismic force acting on other building parts, such as parapets, also needs to be considered appropriately, by setting localized seismic intensities separately. Notification No.1389 of 2000, which is based on the provisions of Article 129-2-4 of the E.O., establishes a standard for structural calculations that include seismic forces for water tanks and other structures projecting from the roofs of buildings.

(2) Article 88, paragraph (2) of E.O. stipulates that the value of the standard shear force coefficient shall be at least 0.2 for calculations of allowable unit stress under the provisions of Article 82 of E.O., and for calculations of inter-story drift angle under the provisions of Article 82-2. The coefficient shall be at least 0.3 for wooden buildings (excluding those that comply with the provisions of Article 46, paragraph (2), item (i) of E.O.) in areas with extremely soft ground, as specified by the specific administrative office under the standards stipulated in Notification No.1793, item (iv) of 1980.

(3) Article 88, paragraph (3) of E.O. stipulates that the standard shear force coefficient ($\boldsymbol{C_0}$) shall be at least 1.0 (under the provisions of Article 82-3, item (ii) of E.O.) when the required ultimate lateral strength is calculated.

(4) The provisions of Article 88, paragraph (4) of E.O. refer to seismic force acting on the underground portion of a building. Since the underground and above-ground portions of a building have different vibration characteristics, seismic force shall be calculated using horizontal seismic intensity ($\boldsymbol{k}$) according to the depth from the ground surface. Seismic layer shear force in the underground portion is, in principle, determined by adding seismic layer shear force transmitted from the above-ground structure to seismic force calculated from horizontal seismic intensity.

2) Explanation of Coefficients

(1) Earthquake Region Coefficient

The earthquake region coefficient ($\boldsymbol{Z}$) is a numerical value representing the probability of seismic motion, based on past records and other data. Figures ranging from 1.0 to 0.7 are specified for each region. The probability of seismic motion is determined by statistically processing large volumes of research findings and interpreting the results from an engineering perspective to determine an earthquake region coefficient ($\boldsymbol{Z}$) for each administrative district. Figure 5.5-3 summarizes the results in map form. When designing actual buildings, it is necessary to take into account the conditions surrounding areas and other factors, and to take any measures that may be required, such as increasing the seismic story shear force coefficient.

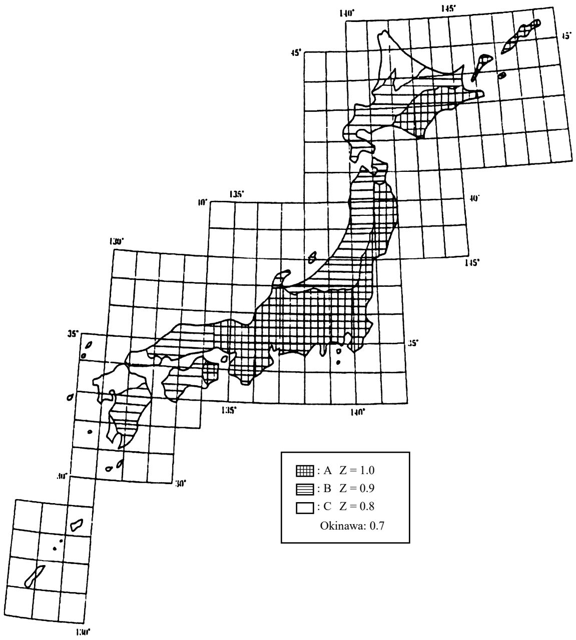

Figure 5.5-3: Earthquake Region Coefficient

(2) Vibration Characteristic Coefficient

The vibration characteristic coefficient ($\boldsymbol{R_t}$) is used to reduce the seismic force value according to the vibration characteristics of a building based on the natural period in the elastic range of buildings, and according to the type of ground, as shown in the following formula. A proviso states that the value can be calculated on the basis of special surveys or studies. However, it shall not be less than 3/4 of the value as determined using the following formula. Figure 5.5-4 plots the values of $\boldsymbol{R_t}$.

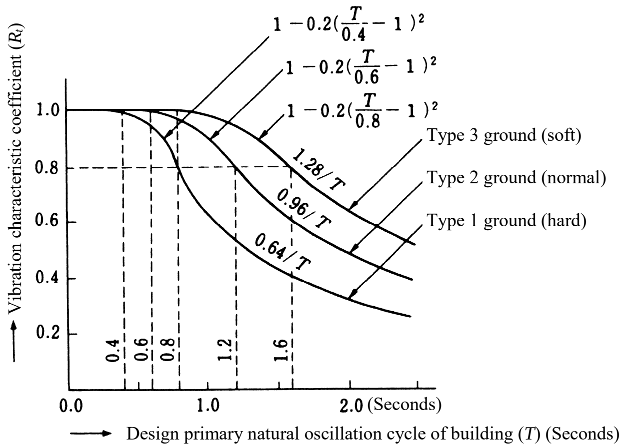

Figure 5.5-4: Vibration Characteristic Coefficient

In case $T < T_c$ $R_t = 1$

In case $T_c \le T < 2T_c$ $R_t = 1 - 0.2\left(\dfrac{T}{T_c - 1}\right)^2$

In case $T < T_c$ $R_t = 1.6\dfrac{T}{T_c}$

where, T represents the natural period (unit: seconds) of the building, as calculated using the following formula.

$\boldsymbol{T} = \boldsymbol{h}\,(0.02 + 0.01\boldsymbol{\alpha})$

where, $\boldsymbol{h}$ represents the height of the building (unit: meters), and $\boldsymbol{\alpha}$ represents the total height of stories in which the majority of columns and beams are made of wooden construction or steel construction (excluding the ground floor) as a ratio of the total building ($\boldsymbol{h}$).

$\boldsymbol{T_c}$ is a value (unit: seconds) based on the type of ground directly beneath the building's foundation (at the tips of rigid support piles, if used), as shown in the following table.

Table : Ground Types and their Definitions

Ground Type	Ground Definitions	T_c
Type 1 Ground	Ground consisting mainly of rock mass or hardened gravel beds from the Tertiary Era or earlier, or ground that has been shown on the basis of surveys or studies concerning ground periods, etc., to have a ground period that is equivalent to these	0.4
Type 2 Ground	Ground types other than Type 1 and Type 3	0.6
Type 3 Ground	Alluvial layers consisting mainly of humus, mud or similar materials (including embankments, if these are present), to a depth of approximately 30 meters or more, marshland or mud sea, etc., filled to a depth of approximately 3 meters or more within a period of approximately 30 years, or ground that has been shown on the basis of surveys or studies concerning ground periods, etc., to have a ground period that is equivalent to these	0.8

(3) Coefficient Representing Seismic Shear Force Distribution

The coefficient representing the seismic shear force coefficient distribution ($\boldsymbol{A_i}$) is along the height calculated using the following formula. $\boldsymbol{A_i}$ is shown in Figure 5.5-6.

$$A_i = 1 + \left(\frac{1}{\sqrt{\alpha_i}} - \alpha_i \right) \frac{2T}{1+3T}$$

where, $\boldsymbol{\alpha_i}$ is a value calculated by dividing the sum of dead loads and live loads (together with snow load in heavy snow areas specified by the specific administrative office under the proviso to Article 86, paragraph (2) of E.O.) in the parts that support the part of the building at the height for which $\boldsymbol{A_i}$ is to be calculated by the sum of dead loads and live loads in the above-ground portion of the building.

The value of $\boldsymbol{A_i}$ increases in proportion to the height of the floor in the building and the value of the natural period ($\boldsymbol{T}$) for the building. If the building is extremely rigid (i.e. if $\boldsymbol{T}$ is extremely small), the entire building from top to bottom will move as a single rigid body, and the seismic story shear force coefficient will be uniform (equivalent to $\boldsymbol{T}$=0 in Figure 5.5-6). In a high-rise building, the seismic story shear force coefficient will increase in proportion to the height of the floor. This tendency increases in proportion to the length of the natural period of the building (equivalent to $\boldsymbol{T}=\infty$ in Figure 5.5-6).

The coefficient, $\boldsymbol{\alpha_i}$, is the ratio of the weight of the portion above a given floor to the weight of the entire building. It represents non-dimensional height to account for the phenomenon that the distribution of seismic force within buildings of the same height will vary according to the weight distribution of each building in the direction of height.

The value of A_i can be calculated on the basis of special surveys or studies. It can also be calculated using modal analysis as the square root of the sum of squares of the contributions of each seismic vibration mode. In this case, it is necessary to standardize the value of A_i as A_1=1. The vibration characteristic coefficient (R_t) can be used as the acceleration response spectrum. It is also possible to use an acceleration response spectrum ratio that properly takes ground amplification into account, as stipulated in Item (4) of Notification No.1461 of 2000. In these cases, it is necessary to calculate T using a method that is at least equivalent to eigenvalue analysis in terms of precision.

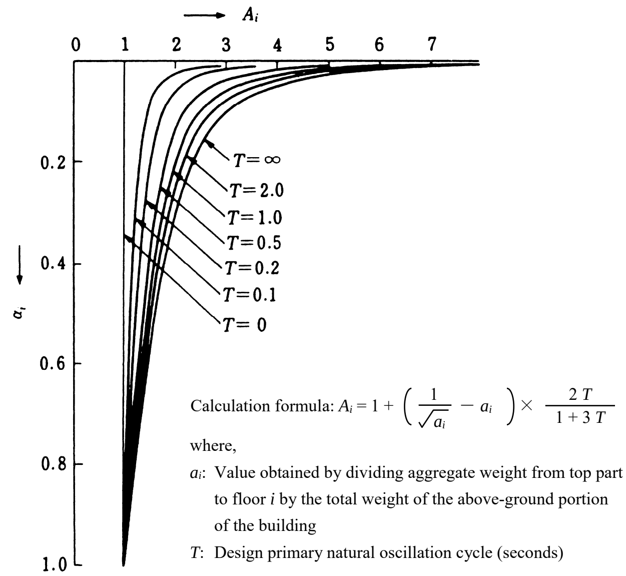

Figure 5.5-6: Distribution Factor of Seismic Layer Shear Force Coefficient

(4) Horizontal Seismic Intensity in Underground Portion of a Building

Figure 5.5-2 shows the distribution of horizontal seismic intensity (***k***) in the underground portion of a building by depth from the ground surface. Many aspects of the behavior of the underground portion of a building during earthquakes have yet to be elucidated. However, observations during earthquakes have shown that the response acceleration in the underground structure decreases as depth increases. The minimum value of ***k*** is therefore constant in regions with an earthquake region coefficient of ***Z***=1.0, at ***k***=0.1 at ground level, ***k***=0.05 at 20 m below ground, and ***k***=0.05 at depths below 20 m.

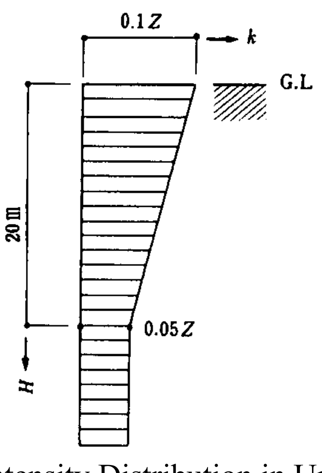

Figure 5.5-2: Horizontal Seismic Intensity Distribution in Underground Portion of a Building

Chapter 6: Structural Designs Based on Calculations of Allowable Unit Stress and Ultimate Strength (CALSUS)

6.1 Calculations of Allowable Unit Stress

Article 82 of the Enforcement Order

(Calculation of Allowable Unit Stress, etc.)

Article 82. Calculations of Allowable unit stress, etc. as specified in Article 81, paragraph (2), item (i), (a) shall refer to a structural calculation that conforms to each of the following items and to the provisions of Article 82-2 through Article 82-4:

(i) Such forces acting upon principal parts of buildings necessary for structural strength (PSE, principal structural elements) as caused by loads and external forces as specified in Clause 2 shall be calculated.

(ii) Unit stresses due to sustained and temporary loads acting upon the sections of principal parts necessary for structural strength as mentioned in the preceding item shall be calculated by the formula shown in the following table.

Force due to sustained loads	Conditions of loads and External forces	General Cases	In heavy snow areas designated by the Designated Administrative Agency under the proviso to Article 86, paragraph (2)	Remarks
Force due to sustained loads	Normal time	G+P	G+P	
	Snow season		G+P+0.7S	
Force due to temporary loads	Snow season	G+P+S	G+P+S	
	Storm	G+P+W	G+P+W	Safety in case of overturning of buildings or pulling out of columns, P shall be a value obtained by reducing the live load according to the actual conditions of the building concerned
			G+P+0.35S+W	
	Earthquake	G+P+K	G+P+0.35S+K	

In this table, G, P, S, W and K represent the following forces (axial force, bending moment, shearing stress and others):

G Forces produced by dead load as specified in Article 84
P Forces produced by live load as specified in Article 85
S Forces produced by snow load as specified in Article 86
W Forces produced by wind pressure as specified in Article 87
K Forces produced by seismic force as specified in Article 88

(iii) It shall be confirmed that unit stresses due to sustained and temporary loads calculated under the preceding item for each PSE in item (i) do not exceed the allowable stresses of sustained forces or temporary forces as specified in Clause 3.

(iv) In cases specified by the Minister of Land, Infrastructure, Transport and Tourism (the Minister), it shall be confirmed by a method specified by the Minister, that any deformation or vibration of structural members constituting PSE will not have any trouble for the use of the building concerned.

(i) Article 82 stipulates that calculations of allowable unit stress (CALS) procedures, etc., are as defined in Article 82 and from Article 82-2 to Article 82-4. Items (i) through (iii) of Article 82 define the methods used to calculate allowable unit stress (AUS). The methods used to calculate the stresses acting upon each member are not stipulated. This means that any reasonable method based on engineering concepts or an original method developed by the designer can be used to calculate stresses and cross-sections. In general, stress analyses are based on the elasticity and stiffness of members.

(ii, iii) Specifically, it is necessary to determine the stresses acting upon each member due to the combination of sustained dead loads, live loads, snow load, wind pressure and seismic force on a sustained or temporary basis (Articles 84-88), and to confirm that the resulting stress does not exceed the AUS for the materials used in each member (Articles 89-94).

(iv) Based on Article 82, item (iv) of the E.O., Notification No. 1459 of 2000 stipulates the circumstances in which it is necessary to examine adverse effects in terms of the use of a building, and the confirmation methods to be used.

This Notification stipulates requirements for parts that are necessary for structural strength (floor beams, floor panels), including the height of beams in relation to span, and the thickness of floor panels. If these requirements are not met, structural calculations shall be carried out to confirm that there will be no trouble for use of the building. Specifically, it shall be confirmed that the maximum bending of beams or floor panels does not exceed 1/250 under considering a creep effect, under loads (dead and live loads) that are constantly acting on the building. Calculations can be based on actual load conditions, or on the figures stated in the tables in Article 85 of the E.O.. The influence of creep can be determined using the figures in the table in Article 2, item (ii) of the Notification, or on the basis of creep test results. Bending is defined here as the amount of deformation from the horizontal plane. If beams or floor panels have a camber, that fact can be taken into account in the calculations.

6.2 Seismic Calculation Methods for Ultimate Strength

6.2.1 Seismic Calculation Methods

In addition to calculations based on the provisions of Article 82 of the E.O., calculations of ultimate strength are also used to confirm safety against earthquakes. There are three calculation procedures (rules), which vary according to differences in the building types.

① Route [1]

Route [1] is used for relatively small buildings other than the specified buildings. This procedure will complete seismic calculations with just CALSUS based on Article 82 of the E.O.. However, the aim is to ensure seismic performance by increasing anticipated seismic force and confirming failure prevention measures for brace ends and joints for steel structures, and by ensuring sufficient wall and column horizontal sectional area for reinforced concrete and steel and reinforced concrete structure (Notification No. 593 of 2007).

② Route [2]

Route [2] is applied to specified buildings of 31m or less in height. In addition to the structural calculations stipulated in Article 82 of the E.O., the following calculations are also included.

a) It shall be confirmed that each inter-story drift angle as a result of seismic force would not exceed 1/200 (1/120 if there is no serious damage resulting from deformation of structures) (Article 82-2 of the E.O.).
b) It shall be confirmed that the stiffness ratio for each story is 0.6 or higher (Article 82-6, item (ii), (a) of the E.O.).
c) It shall be confirmed that the eccentricity ratio for each story does not exceed 0.15 (Article 82-6, item (ii), (b) of the E.O.).
d) In addition to the above, calculations specified for each type of structure by the Minister shall also be carried out. (See Notification No. 1791 of 1980 concerning wooden structures (Section 6.6.2), steel structures (Section 6.3.3), and reinforced concrete structures (Section 6.4.3).)

The aim of designs based on Route [2] is to ensure safety against extremely large earthquakes by reducing stiffness distribution and eccentricity along the height, and by ensuring adequate levels of strength, stiffness and ductility using relatively simple concepts.

③ Route [3]

Route [3] represents the seismic calculation route for specified buildings over 31 m in height, and for specified buildings up to 31m in height that are not based on Routes [1] and [2] above. This route involves the following calculations in addition to the calculations stipulated in Article 82 of the E.O..

a) It shall be confirmed that the inter-story drift angle on each story as a result of seismic force would not exceed 1/200 (1/120 if there is no serious damage resulting from deformation of structures) (Article 82-2 of the E.O.).
b) It shall be confirmed through calculations that ultimate lateral strength on each story is equal to or larger than the required level (Article 82-3 of the E.O.).

The purpose of Route [3] is to assess the energy absorption capacity based on the elasto-plastic behavior (damping, ductility, etc.) of the building during earthquakes, using a coefficient (D_s), and to ensure safety during extremely large earthquakes by providing sufficient energy absorption capacity that will exceed seismic energy inputs.

When calculating ultimate lateral strength, it is necessary to model the frame appropriately and to select a suitable calculation method for the modeled structure.

6.2.2 Inter-story Drift Angle

Article 82-2 of the Enforcement Order

(Inter-story Drift Angle)

Article 82-2. Regarding buildings specified by the Minister (referred to in this Clause as "specified buildings"), it shall be confirmed that, in addition to complying with the provisions of each item of the preceding Article, the ratio of horizontal relative story displacement caused to each aboveground story of a specified building by such seismic force as specified in Article 88, paragraph (1) (referred to in this Clause as "seismic force") to the height of the story concerned (such ratio to be referred to in Article 82-6, item (ii), (a) and Article 109-2-2 as "relative story drift angle") is not greater than 1/200 (1/120 in cases where such deformation of principal parts of a specified building necessary for structural strength as caused by seismic force is not likely to lead to considerable damage of any part of the said building).

This Article applies to seismic designs based on Routes [2] and [3]. It requires confirmation of inter-story drift angle in response to maximum structural plane deformation. The inter-story drift angle used to determine the stiffness ratio is based on the value obtained at the center of stiffness.

6.2.3 Stiffness Ratio, Eccentricity Ratio, etc.

Article 82-6 of the Enforcement Order

(Stiffness Ratio, Eccentricity Ratio, etc.)

Article 82-6. Calculations of Allowable unit stress, etc. as specified in Article 81, paragraph (2), item (ii), (a) shall refer to a structural calculation that conforms to each of the following paragraphs.

(i) is omitted.

(ii) It shall be confirmed that all the aboveground parts conform with each of the following items.

(a) It shall be confirmed that the stiffness ratio of each story to be obtained by the following formula is 6/10 or more.

$$R_s = \frac{rs}{\overline{rs}}$$

where,

R_s : Stiffness ratio of each story

rs : Reciprocal of the relative story drift angle of each story

$\overline{rs}$: Arithmetic mean of all rs's of the specified building concerned

(b) It shall be confirmed that the eccentricity ratio of each story to be obtained by the following formula does not exceed 15/100.

$$R_e = \frac{e}{r_e}$$

where,

R_e : Eccentricity ratio of each story

e : Distance between the gravity centroid and the stiffness centroid of dead and live loads (snow load in addition in heavy snow areas designated by the Specific Administrative Office under the proviso to Article 86, paragraph (2)) acting upon the principal parts necessary for structural strength on each story (in centimeters)

r_e : Square root of a quotient to be obtained by dividing the torsional stiffness around the center of stiffness on each story by a value of horizontal stiffness of the same story in the direction of calculation (in centimeters)

(iii) is omitted.

(ii) If there are variations in horizontal stiffness on each floor, deformation and damage in the event of an earthquake will tend to be concentrated on the floor with the lowest stiffness. Item (a) stipulates the use of stiffness ratios for all stories so that the stiffness of each story is almost equal. To fulfill the requirements of this item, it is advisable to avoid radical changes in stiffness ratios between adjoining stories, since this could result in undesirable vibration patterns.
If walls, columns and other elements that are effective against earthquakes are not arranged appropriately on each floor, there is a danger of torsional vibration, leading to serious structural damage. Item (b) stipulates that the eccentricity ratio (Re), which is defined as an indicator of susceptibility to torsional vibration, on each floor shall not be excessive. The eccentricity ratio is calculated by dividing the eccentricity distance (e) for each floor by the elasticity radius (r_e).

This Article applies to the seismic design of buildings using Route 2. Regarding specified buildings which do not exceed 31m in height, it shall be confirmed that all the aboveground parts conform with each of the items, in addition to the provisions of the items of Article 82 and the preceding Article. If the building does not meet these requirements, ultimate lateral strength shall be confirmed according to the following provision in Route 3.

6.2.4 Ultimate Lateral Strength

Article 82-3 of the Enforcement Order

(Ultimate Lateral Strength)

Article 82-3. It shall be confirmed that the lateral strength against lateral forces in each story calculated according to the provisions of item (i) (hereinafter referred to as the "ultimate lateral strength" in this article and Article 82-5) of all the aboveground parts of the specified building concerned is equal to or greater than the ultimate lateral strength required as calculated according to the provisions in item (ii):

(i) The ultimate lateral strength shall be calculated based on material strength as specified in Clause 4.

(ii) A required value of ultimate lateral strength of each story against seismic force shall be calculated with the following formula.

$$Q_{un} = D_s F_{es} Q_{ud}$$

where,

$\boldsymbol{Q_{un}}$: Required value of ultimate lateral strength of each story (in kilo-Newton)

$\boldsymbol{D_s}$: A value representing structural characteristics of each story specified by the Minister according to the construction method of principal parts necessary for structural strength of specified buildings dumping and ductility of each story

$\boldsymbol{F_{es}}$: A value representing form characteristics of each story to be obtained with a calculation method as specified by the Minister according to stiffness ratio and eccentricity ratio of each story

$\boldsymbol{Q_{ud}}$: Lateral force acting upon each story due to seismic force (in kilo-Newton)

(1) Ultimate Lateral Strength and Required Ultimate Lateral Strength

Strength at Point A in Figure 6.2-6 is represented as $\boldsymbol{Q_{ud}}$. The structural characteristics coefficient D_s reduces the maximum horizontal resistance required in a building to reflect the building's inelastic deformation capacity and other structural characteristics. Figure 6.2-6 shows the result when strength at Point A is reduced to Point C due to the deformation capacity of the building.

Required ultimate lateral strength ($\boldsymbol{Q_{un}}$) is represented by the following formula.

$$Q_{un} = D_s \cdot F_{es} \cdot Q_{ud}$$

$$Q_{ud} = Z \cdot R_t \cdot A_i \cdot C_o \cdot W$$

$$C_o \geqq 1.0$$

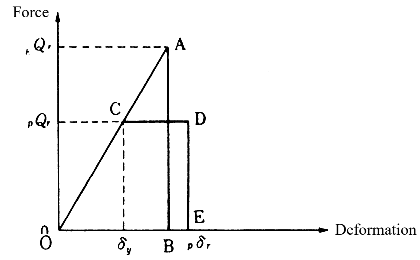

Figure 6.2-6: Energy Absorption During an Earthquake

Vertical or horizontal unevenness of the columns and bearing walls will cause a significant concentration of seismic energy on stories or seismic elements characterized by such marked unevenness. The form coefficient (***F_{es}***) is used to ensure the uniform distribution of seismic energy to all floors by increasing the strength on floors characterized by such marked unevenness. Fes is defined as the product of the stiffness ratio and the eccentricity ratio.

(2) Calculating Method of Ultimate Lateral Strength
Item (i) of this Article requires the ultimate lateral strength for each story to be calculated based on the strength of materials (Articles 95-99) and the calculation method specified by the Minister (Notification No. 596-4 of 2007). Ultimate lateral strength is determined as the sum of horizontal shear forces acting on columns, bearing walls and braces on each floor when a collapse mechanism is formed (including a partial collapse resulting from vertical load caused by the collapse of specific members) through the effect of seismic force on all or part of a building. It is calculated using an appropriate analysis method according to the framework collapse mechanism on each story.

① Basic Principles for Calculation of Ultimate Lateral Strength
In principle, ultimate lateral strength should be calculated using an appropriate analysis method under the following conditions.

a) The assumed distribution of external forces is based on a horizontal distribution of external forces that approximates the action of seismic forces.
b) Conditions of balance are achieved between the effective load and forces acting upon the various parts of the building as required.
c) The forces acting upon parts of the building do not exceed the ultimate strength of members in any part of the building.
d) All or part of the building meets the conditions for the formation of collapse mechanisms. Building collapse mechanisms deemed to be form when the conditions such as the following are met.

    i) When an inelastic hinge sufficient to cause structural instability in the entire building is formed
    ii) When an inelastic hinge sufficient to cause structural instability in part of a particular story in the building is formed
    iii) When a particular member in the building fails, allowing vertical loads to cause a localized vertical collapse even though the building may withstand further increases in horizontal load

    However, in situations where structural strength is dominated by rising motion resulting from the overturning moment of the entire building, as in the case of box frame structures in which the overall length in the span direction is short, this rising motion does not need to be considered in assuming the formation of a collapse mechanism.

② Other Considering Matters Required

Other important factors concerning ultimate lateral strength that are not included in the above principles are as follows.

a) Ultimate lateral strength should, in principle, be measured on two diagonally intersecting horizontal directions in the building.
b) Except in special circumstances, it is not necessary to consider the effect of vertical seismic motion in a vertical direction when calculating ultimate lateral strength. However, due consideration should be given to this factor in calculations in large-span structures, for example.
c) Ultimate lateral strength should also be considered in relation to foundations and underground structures, such as foundation slabs and piles. However, this requirement does not apply if no major problems are anticipated.
d) It is necessary to consider the effect of bending moment in columns and beams under sustained loads on ultimate lateral strength, in special cases, such as large-span beams.
e) In buildings with members made of materials that are prone to brittle fracture, lateral retained strength shall be calculated as the sum of horizontal shear forces acting on each member in the state of deformation that will develop when such fractures occur.

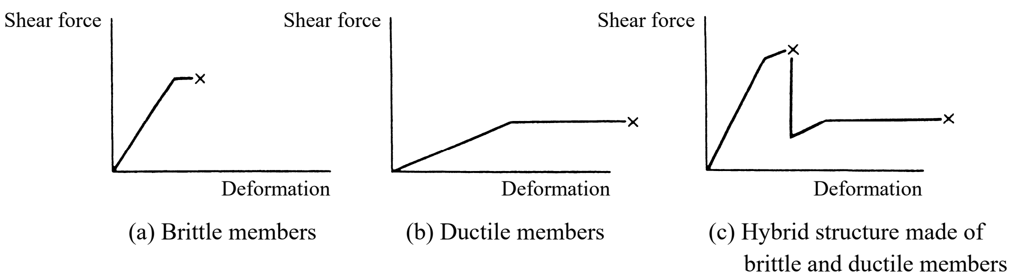

Figure 6.2-8: Restoring Force Characteristics of Members

For example, a hybrid structure consisting of brittle members that have minimal ductility and develop little deformation before breaking, as shown in Figure 6.2-8(a), and highly ductile members that develop substantial deformation before breaking, as shown in Figure 6.2-8(b), will typically have the restoring force characteristics shown in Figure 6.2-8(c).
D_s and ultimate lateral strength in such cases should be reflected in designs as follows.

i) Taking brittleness into account
With this method, designs are based on the level of deformation at which brittle members will break. The ductility of brittle materials is taken into account when determining D_s. Since ultimate lateral strength upon breaking (or deformation upon breaking) of brittle members will be calculated, the strength of ductile members shall be reduced according to the shear force resulting from deformation.
ii) Disregarding brittle members
With this method, designs are based on the level of deformation at which ductile members break. Even if a brittle member fails, there is no risk of partial building collapse if the surrounding members are able to bear the vertical force previously sustained by the broken brittle member. In such cases, the presence of the brittle

members can be ignored, and the value of $\boldsymbol{D_s}$ can be determined, and ultimate lateral strength calculated, as if the building consisted solely of ductile members. An example to which this method can be applied is a building in which there are many ductile members with just a few brittle members used additionally.

(3) Structural Characteristics Coefficient ($\boldsymbol{D_s}$) and Form Coefficient ($\boldsymbol{F_{es}}$)
The structural characteristics coefficient ($\boldsymbol{D_s}$), which is a reduction factor reflecting the seismic force absorption capacity, etc., based on its deformation capacity, is explained in Section 6.3 (S structures), Section 6.4 (RC structures) and Section 6.6 (wooden structures). The range of $\boldsymbol{D_s}$ values is 0.25-0.5 in S structures and wooden structures, 0.3-0.55 in RC structures. The form coefficient ($\boldsymbol{F_{es}}$), which is an increase factor based on structural form characteristics, is explained below.

Notification No. 1792 of 1980
(amended by Notification No. 596 of May 18, 2007)

Determination of Methods for Calculation of $\boldsymbol{D_s}$ and $\boldsymbol{F_{es}}$

The following methods have been established for the calculation of $\boldsymbol{D_s}$ and $\boldsymbol{F_{es}}$ under the provisions of Article 82-3, Item (ii) of the Building Standard Law Enforcement Order (E.O.) (No. 338 of 1950).

1. Method for Calculation of $\boldsymbol{D_s}$
The $\boldsymbol{D_s}$ value for each story in buildings is calculated using the values in the following 2, 3, 4, 5 and 6 in the case of stories on which columns and beams are mostly of wooden construction, steel construction, reinforced concrete construction, steel reinforced concrete construction and other constructions, respectively. If the damping effect and ductility of each story in relation to the vibration of the building concerned can be determined appropriately based on the results of special investigation or research, the results of these calculations may be used.

2-6. are omitted.

7. Method for Calculation of $\boldsymbol{F_{es}}$
The $\boldsymbol{F_{es}}$ for each story of a building shall be calculated by multiplying the value of $\boldsymbol{F_s}$, as shown in Table 1 below, which corresponds to the stiffness ratio as defined in Article 82-6, item (ii), (a) of the E.O., by $\boldsymbol{F_e}$, as shown in Table 2 below, which corresponds to the eccentricity ratio as defined in Article 82-6, item (ii), (b) of the E.O.
Proviso: If it is possible to calculate $\boldsymbol{F_{es}}$ based on an appropriate assessment of the relationship between the stiffness and eccentricity ratio for a story and the building's form characteristics, it shall be acceptable to use that calculation.

1

Stiffness Ratio		Value of $\boldsymbol{F_s}$
(1)	If $R_s \geq 0.6$	1.0
(2)	If $R_s < 0.6$	$2.0 - \frac{R_s}{0.6}$
In this table, R_s represents the stiffness ratio for each story.		

2

Eccentricity Ratio		Value of $\boldsymbol{F_e}$
(1)	If $R_e \leq 0.15$	1.0
(2)	If $0.15 < R_e < 0.3$	A value obtained through linear interpolation based on the values in (1) and (3)
(3)	If $R_e \geq 0.3$	1.5
In this table, R_e represents the eccentricity ratio for each story.		

Chapter 7: Structural Designs Based on Calculations of Response and Limit Strength
7.1 Calculations of Response and Limit Strength (CARLS)

Article 82-5 of the Enforcement Order

(CARLS)
Article 82-5 CARLS specified by the provisions of Article 81, paragraph (2), item (i), (b) shall refer to structural calculations specified as follows.

(i) Except during an earthquake, it shall conform to the provisions from Article 82, item (i) to item (iii) (excluding parts related to earthquakes).

(ii) The forces generated in structural elements necessary for resistance (PSE) of a building during a snow or strong winds shall be calculated by the formula shown in the following table and it shall be confirmed that the forces generated in the principal parts necessary for structural strength do not exceed the strength of the principal parts necessary for structural strength calculated according to the material strengths based on the provisions of Clause 4.

Combination of Load and External Forces

Conditions of the loads and external forces	Ordinary case	In heavy snow areas designated by the designated administrative agency under the proviso to Article 86, paragraph (2)	Remarks
Extremely heavy Snow	$G+P+1.4S$	$G+P+1.4S$	
Extremely strong Storm	$G+P+1.6W$	$G+P+1.6W$	When the overturning of a building, pull-out of a column, etc. is studied, P shall be based on a value obtained by reducing the live load according to the actual state of the building.
		$G+P+0.35S+1.6W$	

In this table, *G*, *P*, *S*, and *W* represent the following forces (axial force, bending moment, shearing force and others):

G Forces produced by dead load as specified in Article 84
P Forces produced by live load as specified in Article 85
S Forces produced by snow load as specified in Article 86
W Forces produced by wind pressure as specified in Article 87

(iii) The seismic forces acting on each above-ground story of a building and the story drift generated in each story of the building by the acceleration of an earthquake shall be calculated as specified in the following, it shall be confirmed that the seismic forces do not exceed the damage limit strength (refers to the strength against horizontal forces in each story of the building in a case where the unit stress generated in the cross-sections of principal parts necessary for structural strength in each story of the building reaches the allowable unit stress against the temporary force generated based on the provisions in Clause 3; hereinafter refers to as same in this item), and it shall be confirmed that the story drift does not exceed 1/200 of the height of the stories (In a case where there is no danger of conspicuous damage in a part of the building, 1/120 of the story drift is permitted).

(a) The story drift when the story is withstanding horizontal force equivalent to the damage limit strength and other forces acting on it (referred to as "damage limit drift" in the remainder of this item) shall be calculated by a method specified by the Minister of Land, Infrastructure, Transport and Tourism (the Minister).
(b) The equivalent natural period of a building when a story drift equivalent to the damage limit drift calculated in a) is generated in any story of the building (referred to as "damage limit natural period" in this item and item (vii)) shall be calculated by a method specified by the Minister.
(c) The seismic force acting on a story of a building during an earthquake shall be calculated as the summation of the lateral forces generated in the story and higher stories calculated by the formula shown in the following table based on the damage limit natural period.

If $Td < 0.16$	$Pd_i = (0.64 + 6\ Td)\ m_i\ Bd_i\ Z\ Gs$
If $0.16 \leq Td < 0.64$	$Pd_i = 1.6\ m_i\ Bd_i\ Z\ Gs$
If $Td \leq 0.64$	$Pdi = \frac{1.024\ mi\ Bdi\ Z\ Gs}{Td}$

In this table, ***Td***, Pd_i, m_i, Bd_i, ***Z***, and ***Gs*** represent the following values.

Td Damage limit natural period of the building (unit: seconds)
Pd_i Lateral forces acting on each story (units: kilo-Newton)
m_i Mass of each story (the sum of the dead load and the live load (plus the snow load in heavy snow areas designated by the Designated administrative agency under the proviso to Article 86, paragraph (2)) of the story) (unit: tons)
Bd_i A value that represents the distribution of the acceleration generated in each story of the building and is calculated in accordance with standards specified by the MLIT based on its damage limit natural period
Z Value of ***Z*** which is stipulated in Article 88, paragraph (1)
Gs A value that represents the amplification factor of the acceleration caused by the surface soil and is calculated by a method specified by the Minister according to the type of surface soil

(d) The story drift generated when the story is withstanding seismic force and other forces acting on it calculated in (c) shall be calculated by a method specified by the Minister.

(iv) The unit stress generated in the cross section of principal parts necessary for structural strength of the below-ground parts of a building by the seismic force stipulated in Article 88, paragraph (4) shall be calculated based on the provisions of Article 82, item (i) and item (ii), and it shall be confirmed that these do not exceed the allowable unit stresses for the temporary forces in accordance with the provisions of Clause 3.
(v) The seismic force acting on each story of a building under the effects of acceleration generated by an earthquake shall be calculated by methods stipulated below and it shall be confirmed that the seismic force does not exceed the ultimate lateral strength of the building.

(a) The maximum story drift when the story is withstanding horizontal force equivalent to the ultimate lateral strength and other forces acting on it (hereinafter referred to as “safety limit drift” in the remainder of this item) shall be calculated by a method specified by the Minister.
(b) The equivalent natural period of a building when displacement equivalent to the safety limit drift calculated in (a) is generated in any story of the building (referred to as “safety limit natural period” in the remainder of this item) shall be calculated by a method specified by the Minister.
(c) The seismic force acting on each story of a building during an earthquake shall be calculated as the summation of the lateral forces generated in the story and higher stories calculated by the formula shown in the following table based on the safety limit natural period.

If $Ts < 0.16$	$Psi = (3.2 + 30\ Ts)\ m_i\ Bs_i\ Fh\ Z\ Gs$
If $0.16 \leq Ts < 0.64$	$Psi = 8\ m_i\ Bs_i\ Fh\ Z\ Gs$
If $Ts \leq 0.64$	$Psi = \frac{5.12\ mi\ Bsi\ Fh\ Z\ Gs}{Ts}$

In this table, ***Ts***, Ps_i, m_i, Bs_i, ***Fh***, ***Z***, and ***Gs*** represent the following values.

Ts Safety limit natural period of the building (unit: seconds)
Ps_i Lateral forces acting horizontally on each story (units: kilo-Newton)
m_i Value of mi as stipulated in the table in item (iii)
Bs_i A value that represents the distribution of the acceleration generated in each story of the building and is calculated in accordance with standards specified by the Minister based on the properties of the vibration of the safety limit natural period
Fh A value that represents the reduction factor of the acceleration caused by the damping of the vibration at the safety limit natural period and is calculated in accordance with standards specified by the Minister
Z Value of ***Z*** which is stipulated in Article 88, paragraph (1)
Gs Value of ***Gs*** specified in the table in item (iii)

(vi) It shall be in accordance with the provisions of Article 82, item (iv).
(vii) It shall be confirmed that roofing materials, exterior materials and curtain walls to be fixed to the outside of buildings are safe from the viewpoint of structural strength against wind pressure, earthquakes, and other vibrations and impacts based on structural calculations specified by the Minister accounting for the acceleration generated in each story of the building and the story drift in each story of the building calculated in accordance with the provisions of item (iii), (d)).
(viii) It shall be confirmed that the exterior walls etc. of a building with habitable rooms in a Special Warning District will not collapse under the action of the shock that will be caused by a natural disaster by structural calculations that comply with standards stipulated by the Minister according to the type, maximum force, etc. of the natural disaster, and height of the mud and rock, etc. (when the height of the exterior wall etc. is less than the height of the mud and rock, etc., the type, maximum force, etc. of the natural disaster, height of the mud and rock, etc. and height of the exterior walls). Provided that this shall not apply in a case conformed by the proviso to Article 80-3.

CARLS (Article 82-5 of the E.O.) are a structural calculation method established in parallel with existing structural calculations (calculations of allowable unit stress and ultimate strength (CALSUS)) under the amended Building Standard Law Enforcement Order of 2000 (E.O.). CARLS are used to confirm safety by directly examining safety against heavy snow and strong winds that occur on extremely rare occasions, and by calculating the deformation of buildings in earthquakes and the strength required on that basis. While conformance with specification regulations is required in CALSUS, CARLS do not require conformation with specification regulations other than those pertaining to durability (regulations relating to durability, etc., provided in Article 36, paragraph (1) of the E.O..; see Paragraph 2.2.4), which cannot be guaranteed by means of structural calculations.

These provisions are based on the following performance requirements.

① It shall be confirmed that a building will not be damaged under sustained loads, and under heavy snow or strong winds, etc., that are likely to occur at least once during the service life of the building. (Item (i))
Item (i) cites the provisions of Article 82, items (i) through (iii) of the E.O... It requires the same performance as it is confirmed though CALSUS in relation to sustained loads, heavy snow loads and strong wind pressure.

② Verification in relation to extremely heavy snow and extremely strong winds requires confirmation that the building will not collapse or otherwise be destroyed under large loads that will occur on extremely rare occasions. (Item (ii))
Item (ii) requires direct examination of safety against extremely heavy snow and extremely strong winds. This is similar to the methods used to verify ultimate lateral strength in relation to earthquakes. Maximum load is assumed to be a value expected to occur once every 500 years, while heavy snow or strong wind that are likely occur at least once during the service life of the building has a recurrence period of 50 years. The ratios established for snow load and wind pressure are 1.4 and 1.6 respectively. These structural calculations relating to maximum loads are based on inelasticity analyses using material strength.

③ It shall be confirmed that the above-ground parts of buildings will not be damaged in an earthquake that is likely to occur once during the service life of the building. (Item (iii))
Item (iii) defines a seismic calculation method based on the response of the building during earthquakes. This differs from traditional seismic calculations performed as part of CALSUS. Response values are calculated for the building that is reduced to SDOF system using a response spectrum established at an engineering bedrock. The damage limit strengths of all stories are calculated based on the allowable unit stress of the materials and confirm that response shall not exceed the limit. The basic principles of stress calculation are the same as for calculations of allowable unit stress. Calculations should be based on reliable technical data and design information.

④ It shall be confirmed that the underground parts of buildings will not be damaged in an earthquake that is likely to occur once during the service life of the building. (Item (iv))
Item (iv) stipulates the standards required to ensure that the underground parts of a building will have performance equivalent to that confirmed by means of CALSUS.

⑤ It shall be confirmed that the above-ground parts of buildings will not collapse or otherwise be destroyed in an earthquake that will occur on extremely rare occasions. (Item (v))

Item (v) stipulates new structural calculations based on the same approach as in Item (iii), in place of the ultimate lateral strength calculations. Because the ultimate lateral strength of all stories is used as the limit value for the building, the traditional method can be used. However, to calculate response values (lateral displacement), it is necessary to accurately ascertain deformation under these conditions. This requires reliable assessment based on technical data and design information concerning the ductility of the materials.

⑥ It shall be confirmed that usability will not be adversely affected. (Item (vi))
Item (vi) stipulates the standards required to ensure performance equivalent to that confirmed by means of CALSUS. The standards are based on the provisions of Article 82, item (iv) of the E.O.. and the procedure is equivalent to those for the structural calculations that have been carried out in the past.

⑦ It shall be confirmed that roofing materials, etc., are safe in terms of structural strength against wind pressure and earthquakes, etc. (Item (vii))
Item (vii) requires that roofing materials, etc., be safe in terms of structural strength, in the same way as CALSUS. (Article 82-4 of the E.O.). Article 82-4 of the E.O. requires confirmation of safety against wind pressure. Item (iii) of this Notification also requires calculations concerning the response of the building during earthquakes, so it is necessary to carry out structural calculations that take these external forces, etc., into account, provided that the basic principles for stress calculations, etc., are the same as in the past.

⑧ It shall be confirmed that the exterior walls etc. of a building with habitable rooms in a Special Warning District will not collapse under the action of the shock that will be caused by a natural disaster. (Item (viii))

The verification of safety against earthquake motion through CARLS is based on the idea of calculating the response value of a building in an earthquake motion using the equivalent linearization method, thus confirming that the inherent performance (limit value) of the building is greater than that response value. A characteristic of CARLS for this purpose is the fact that the earthquake motion is set in terms of the acceleration response spectrum.
A flowchart for CARLS based on the Enforcement Order (E.O.) and the Notification is provided in the following figure. CARLS are basically used to verify not only the prevention of damage, collapse, or failure, but also to provide direct verification of strength against wind load and snow load as well as earthquake motion. As for live load, it is confirmed that there will be no damage, safety in relation to collapse and failure under live load is automatically ensured, therefore the above-mentioned verification is exempted.

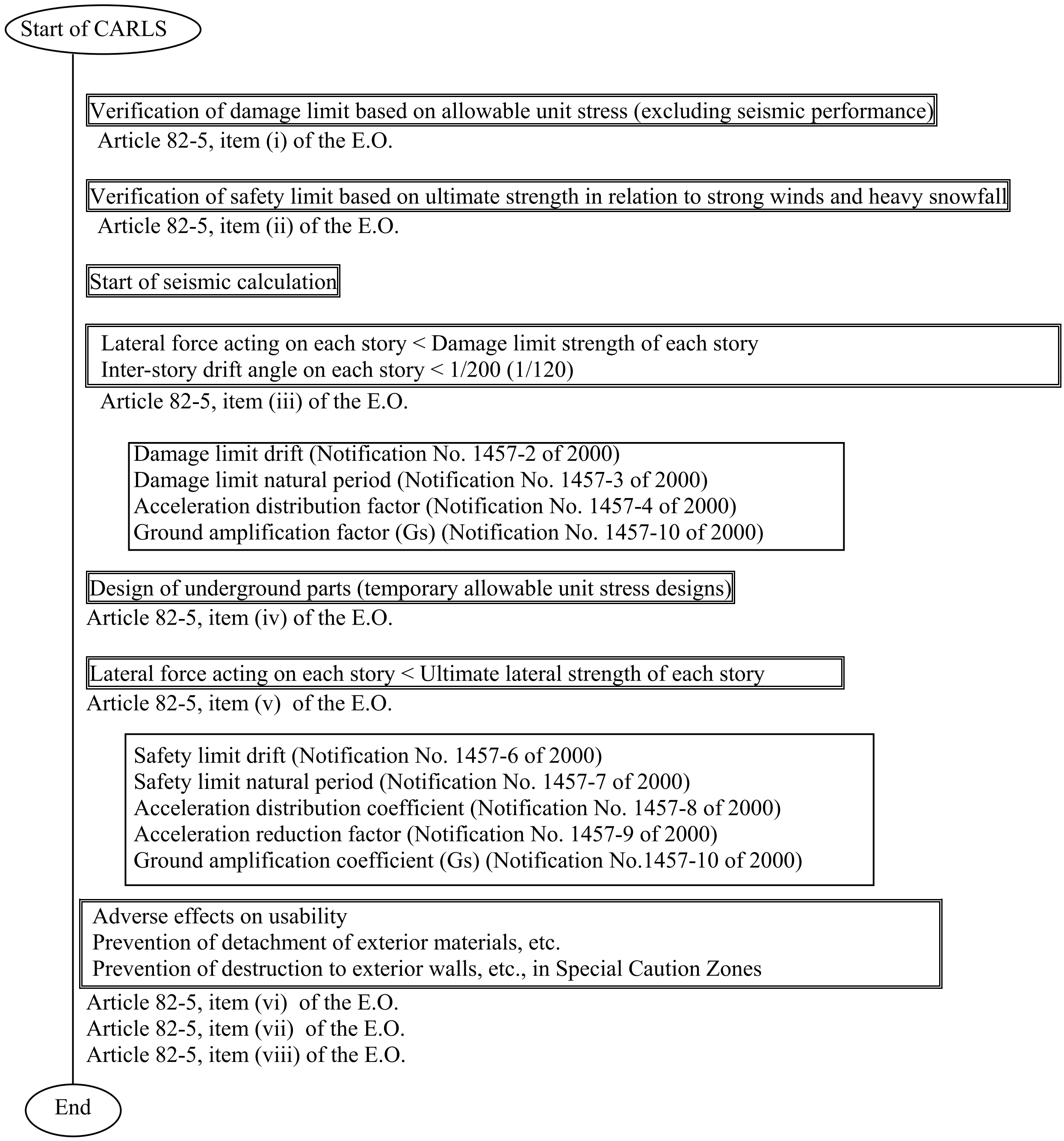

Figure: Flowchart for CARLS in Relation to Seismic Performance

7.2 Example of Application for Seismic Design in CARLS

The following procedures are structural calculations for the extreme strong earthquake motion, as defined in Article 82-5, item (v) of the E.O.. The greatest difference between this approach and ultimate lateral strength calculations as stipulated in Article 82-3 of the E.O. is that the maximum deformation of the building is considered when calculating the seismic force acting on each story.

(a) The maximum story drift when the story is withstanding horizontal force equivalent to the ultimate lateral strength and other forces acting on it (hereinafter referred to as "safety limit drift" in the remainder of this item) shall be calculated by a method specified by the Minister.

(b) The natural period of a building when displacement equivalent to the safety limit drift calculated in (a) is generated in any story of the building (referred to as "safety limit natural period" in the remainder of this item) shall be calculated by a method specified by the Minister .

By determining the horizontal limit deformation at ultimate lateral strength on each above-ground story, it is possible to calculate the natural period for the building in its ultimate state. The actual method is specified by the Minister (Notification No.1457-6,7 of 2000). An equivalent linearization method is used.

① The ultimate lateral strength of each story of the building is calculated, and the deformation on each story when safety limit drift is first reached on any story is determined as the value corresponding to the safety limit drift of the entire building when a lateral force corresponding to that ultimate lateral strength acts on the building.

② The equivalent displacement and effective mass of the building at this time are then determined on the basis of the amount of deformation and mass on each story. A single mass point system can then be substituted for the building.

Effective mass: $Mu_s = \dfrac{\left(\sum m_i \delta s_i\right)^2}{\sum m_i \delta s_i^{\,2}}$, Equivalent displacement: $\Delta s = \dfrac{\sum m_i \delta s_i^{\,2}}{\sum m_i \delta s_i}$

③ The natural period (safety limit natural period) of the building is then calculated on the basis of effective mass, equivalent displacement and lateral force at the safety limit.

Safety limit natural period: $Ts = 2\pi \sqrt{Mu_s \dfrac{\Delta s}{Qs}}$

(c) The seismic force acting on each story of a building during an earthquake shall be calculated as the aggregate of the forces generated horizontally in the story and higher stories calculated by the formula shown in the following table according to the safety limit natural period. (The table is omitted).

The safety limit natural period of the building as calculated in (b) is then used to determine the force acting on the building. This involves calculating the shear force acting on each story of the building based on the amount of deformation at the building's safety limit, using the damping effect of the building (the effect whereby acceleration is reduced as the building suffers damage) and the distribution coefficient (***Bs***$\boldsymbol{Bs_i}$) for acceleration applied to each story. The procedures described in ④ through ⑦ below are then followed.

④ The acceleration (***Sa***) affecting the building is calculated on the basis of the acceleration response spectrum (equivalent to 5% damping) of the engineering bedrock corresponding to an earthquake that will occur on extremely rare occasions, as shown in Table 7.2-1. Factors taken into account in this calculation include the natural period (safety limit natural period, ***Ts***) of the building, and the acceleration amplification coefficient of the subsurface soil (***Gs***).

Table 7.2-1: Strongest Earthquake motion (Values for Engineering Bedrock)

Natural period (Ts) (seconds)	Acceleration response spectrum (m/sec^2)
If ***Ts*** < 0.16	3.2+30×***Ts***
If 0.16≤***Ts***<0.64	8
If ***Ts***≤0.64	5.12/***Ts***

(The result is also multiplied by the earthquake region coefficient ***Z***.)

The following figure shows the acceleration response spectrum on the engineering bedrock. The acceleration response spectrum used to verify safety limits is based on the assumption that the short-period constant acceleration amplitude will be 8 m/s^2, and the long-period constant velocity amplitude will be 0.815 m/s. If the natural period is zero, the acceleration response spectrum will be equal to the maximum time history acceleration amplitude (3.2 m/s^2). The acceleration amplitude has therefore been reduced for the area ranging from one-quarter of the intersecting cycle (0.64 second) to the point where the cycle goes down to zero with both acceleration and velocity being held constant. The damage limit verification level of the acceleration amplitude is one-fifth of the safety limit verification level.

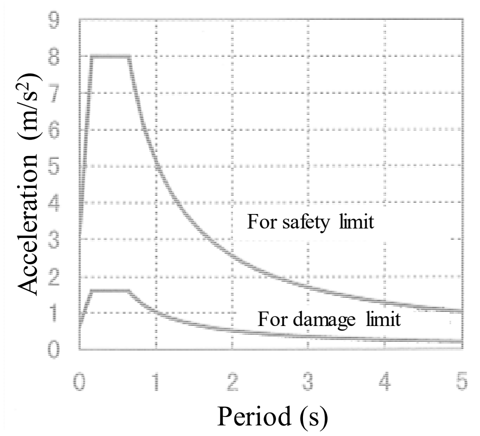

Figure 2.5-1: Standard Acceleration Response Spectrum in an Outcropped Engineering Bedrock

⑤ The acceleration reduction ratio (***Fh***) relative to vibration damping is determined on the basis of the equivalent displacement of the building.

Acceleration reduction factor: $Fh = \dfrac{1.5}{1+10h}$

where, ***h*** is a value representing the damping effect of the building. In principle, it is calculated from the damping effect of individual members.

⑥ The acceleration acting on each story is then determined, and the layer shear force on each story is calculated from the lateral force ($\boldsymbol{Ps_i}$) acting on each story.

⑦ The lateral seismic force (layer shear force) acting on each story is compared with the ultimate lateral strength of each story to confirm the safety of the building in an earthquake that will occur on extremely rare occasions.

With this method it is important to confirm that the stress and deformation affecting individual members at the specified safety limit drift do not exceed the strength and limit deformation of the members, or that the stress and deformation affecting the members at the specified safety limit drift are warranted. When using the above method, however, it is important to note that the earthquake motion acting on the building (required limit strength) does not provide true response values (the strength and deformation of the building as restoring force characteristics).
It is possible, however, to determine true response values directly without repeated calculations by means of the following method (see the following figure). The ***Sd-Sa*** relationship obtained by connecting ***Sd*** and ***Sa*** in the same natural periods for the pseudo-acceleration response spectrum (Sa_1-T, Sa_2-T) and the displacement response spectrum ($Sd_1 = Sa_1/\omega^2$-T, $Sd_2 = Sa_2/\omega^2$-T, $\omega = 2\pi/T$) from which it is derived are compared with the relationship between lateral force and deformation in a construction reduced to a system with SDOF. The intersection between the two curves represents the true response value (• in the diagram). As far as the ***Sd-Sa*** relationship is concerned, the reduction of the response spectrum due to damping means a shorter distance between the intersection and the origin in the graph.

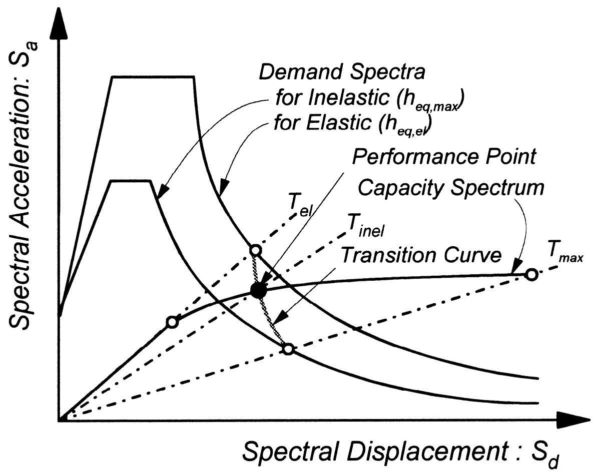

Figure: Assessing Seismic Performance in CARLS

7.3 Seismic Design Method in CARLS

Notification No.1457 of 2000
(amended by Notification No.791 of May 31, 2016)

In accordance with the provisions of Article 82-5, items (iii), (a), (b), (c) and (d), (v), (vii) and (viii) of the Building Standard Law Enforcement Order (Cabinet Order No.338 of 1950), the standard of the methods for calculating damage limit drift, ***Td***, ***Bd$_i$***, story drift, safety limit drift, ***Ts***, ***Bs$_i$***, ***Fh***, ***Gs*** and structural calculation methods for confirming the structural resistance safety on the roof covering materials are hereby certified as follows.

1. Principal of Seismic Design Method in CARLS
2. Damage limit displacement on each story
3. Natural response period at damage limit of buildings (***Td***)
4. Distribution factor of acceleration on each story (***Bd$_i$***)
5. Story drift on each story
6. Safety limit displacement on each story
7. Natural response period at safety limit of buildings (***Ts***)
8. Distribution factor of acceleration on each story (***Bs$_i$***)
9. Reduction rate of acceleration according to the damping of the earthquake motion (***Fh***)
10. Acceleration amplification coefficient of the subsurface ground (***Gs***)
11. Calculation for roofing materials etc.
12. Calculation in earth-flow disaster caution zone

Notification No.1457 of 2000 stipulates the structural calculation methods specified by Article 82-5 for CARLS. Provisions from the 1st to the 10th are related to seismic calculations.

7.3.1 Principal of Seismic Design Method in CARLS

Notification No.1457 of 2000
(amended by Notification No.791 of May 31, 2016)

1. CARLS specified by Article 82-5 of the Enforcement Order shall be conducted by pushover analysis. In addition, it is necessary to confirm no deterioration of story shear force before story drift reaches safety limit drift in each story specified by the 6th provision.

7.3.2 Seismic calculation in CARLS
(1) Calculation for an earthquake that is likely to occur once during the service life of the building

Notification No.1457 of 2000
(amended by Notification No.791 of May 31, 2016)

2. The damage limit displacement on each story in accordance with Article 82-5, item (iii) shall be defined as displacement which is less than the inter-story drift when each story of buildings withstands the lateral force equivalent to the lateral damage limit capacity and other load.

3. The natural response period at damage limit of buildings (***Td***) in accordance with the provisions of Article 82-5, item (iii) of the Enforcement Order shall be calculated by the following formula. Provided that, additional multiplication of the period adjustment factor given by the following provision shall be allowed when the soil characteristics is given by the

soil survey provided by Notification No. 1113, paragraph (1) of 2001.
This calculation method can be applied in case that ***Td*** is calculated by the characteristic value analysis method based on the mass and rigidity of each part of buildings.

$$Td = 2\pi\sqrt{Mu_d \frac{\Delta d}{Qd}}$$

Where,

Td: Natural response period at damage limit (in seconds)

Mu_d: Effective mass of a building given by the following formula, (in ton)

$$Mu_d = \frac{\left(\sum m_i\ \delta d_i\right)^2}{\sum m_i\ \delta d_i^{\,2}}$$

Where,

m_i: the mass in the i-th story

δd_i: the displacements from the i-th story's basement when the lateral force ***Pd_i*** (in kilo-Newton) which is equivalent to the strength at damage limit calculated by the following formula, acts on the i-th story (hereafter "at damage limit of buildings") (in meters)

$$Pd_i = \frac{Bd_i\ m_i}{\sum_{j=1}^{N} Bd_j\ m_j} \cdot Qd$$

Where,

Bd_i: the distribution factor of acceleration based on the second provision

Qd: the strength at damage limit of buildings (in kilo-Newton)

Qd: the strength at damage limit of buildings given by the following condition (in kilo-Newton)

On each story, it shall be calculated as the value obtained by multiplying the minimum value of the base converted shear force coefficient ***qd_i*** of the strength at damage limit given by the following formula and the gross weight of the building.

$$qdi = \frac{Qdi}{\dfrac{\sum_{j=i}^{N} Bd_j \cdot m_j}{\sum_{j=1}^{N} Bd_j \cdot m_j} \cdot \sum_{j=1}^{N} m_j \cdot g}$$

Where,

qd_i: the base converted shear force coefficient of the i-th story's strength at damage limit

Qd_i: the i-th story's strength at damage limit (in kilo-Newton)

Bd_i: the distribution factor of acceleration in accordance with the second provision

m_i: the mass in the i-th story (in tons)

Δd: the equivalent displacement of buildings calculated by the following formula (in meters)

$$\Delta d = \frac{\sum m_i \ \delta d_i^{\,2}}{\sum m_i \ \delta d_i}$$

Where,

M_i: the mass in the i-th story

δd_i: the displacement from the i-th story's basement as specified by the formula of ***Mu_d*** (in meters)

(2) The period adjustment factor shall be calculated by the following formula.

$$r = \sqrt{1 + \left(\frac{Tsw}{Td}\right)^2 + \left(\frac{Tro}{Td}\right)^2}$$

Where,

γ: the period adjustment factor

T_{sw}: the sway natural period (in seconds)

$$Tsw = 2\pi\sqrt{\frac{Mu_d}{K_h}}$$

Where,

Mu_d: the effective mass of buildings defined in the previous clause (in tons)

K_h: the lateral soil spring constant in proportion to the shear strain on the subsurface ground at the earthquake given by the soil research (in m/kilo-Newton)

Td: the response period at damage limit of the buildings determined by the previous clause (in seconds)

T_{ro}: the rocking natural period calculated by the following formula (in seconds)

$$Tro = 2\pi\sqrt{\frac{Mu_d}{K_r}} \cdot H$$

Where,

Mu_d: the effective mass of buildings as specified by the previous clause (in tons)

K_r: the rotating soil spring constant base on the shear strain on the subsurface ground at the earthquake given by the soil research (in radian/kilo-Newton meter)

H: the value obtained by adding the depth of the basement to the base of surface to the height above the ground, of which displacement from the basement of the building is equal to the equivalent displacement of the building as specified by the preceding paragraph.

(3) is omitted.

4. The distribution factor (***Bd_i***) of acceleration on each story in accordance with the table of the Article 82-5, item (iii), (c) is the value which is calculated by the modal participation function according to the natural period at the damage limit, based on the distribution of each story's displacement at the damage limit and is multiplied by ***p*** and ***q*** in the following table.
In case when the building is uniform and homogeneous or less than 5 story, it can be calculated by the formula in paragraph (3) of the following Table using ***Bd_i*** calculated by the formula in paragraph (1), (2) based on the story.

(1)	bd_i (the top floor)	$bd_i = 1 + \left(\sqrt{\alpha_i} - \alpha_i^2\right) \cdot \frac{2h(0.02+0.01\lambda)}{1+3h(0.02+0.01\lambda)} \cdot \frac{\sum m_i}{m_N}$
(2)	bd_i (floors except for the top floor)	$bd_i = 1 + \left(\sqrt{\alpha_i} - \sqrt{\alpha_{i+1}} - \alpha_i^2 + \alpha_{i+1}^2\right) \cdot \frac{2h(0.02+0.01\lambda)}{1+3h(0.02+0.01\lambda)} \cdot \frac{\sum m_i}{m_N}$
(3)	Bd_i distribution factor of acceleration	$Bd_i = pq \frac{Mu_d}{\sum_{j=1}^{N} m_j} \cdot bd_i$

Where,

α_i: the value obtained by dividing the sum of the dead load and the live load of the parts supported by the part of the height which is used to calculated for bd_i of the building (In heavy snow fall region as specified by the Article 86, paragraph (2), snow load shall be added.) by the sum of the dead load and the live load of the buildings above ground.

h: the height of the building (in meters)

λ: the ratio to h of buildings of which the majority of columns and beams are wooden- or steel structure

m_i: the mass in the i-th story

ρ: the value calculated by the formula in the following table based on the number of stories and the response period for damage limit

The natural response period at damage limit / Story	0.16 sec. and less	more than 0.16 sec.
1	$1.00 - \frac{0.20}{0.16} Td$	0.80
2	$1.00 - \frac{0.15}{0.16} Td$	0.85
3	$1.00 - \frac{0.10}{0.16} Td$	0.90
4	$1.00 - \frac{0.05}{0.16} Td$	0.95
More than 5	1.00	1.00
Where, ***Td***: the natural response period at damage limit of the building		

q: the value calculated by the formula in the following table according to the ration of the effective mass to the whole mass of the buildings (hereafter "effective mass ratio").

The ratio of effective mass	Less than 0.75	$0.75 \frac{\sum mi}{Mu_d}$
	0.75 and more	1.0

Where,

Mu_d : the effective mass of buildings defined in the previous clause (in tons)

5 is omitted.

(2) Calculation for an earthquake that will occur on extremely rare occasions

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(amended by Notification No.791 of May 31, 2016)

6. The safety limit displacement on each story in accordance with Article 82-5, item (vi), (a) shall be defined as displacement which is less than the inter-story drift when each story of buildings withstands the lateral force equivalent to the lateral load-carrying capacity and other load. The safety limit displacement on each story can be calculated based on the structural building, provided that no collapse of the building whose materials which have reached the drift angle for limit were removed from is not observed.

$$Ru = Rb + Rs + Rx$$

Where,

R_u: the drift angle for limit of members (in radian)

R_b: the drift angle of members to the bending calculated by the following formula (in radian)

$$Rb = \frac{\varphi_y a}{3} + \left(\varphi_u - \varphi_y\right) l_p \left(1 - \frac{l_p}{2a}\right)$$

Where,

ϕ_y: bending ratio of materials at damage limit (in radian/m)

ϕ_u: the bending ratio in the hinge zone at the maximum strength (in radian/m) Provided that, the strength of members does not deteriorate to the acting force on the member at safety limit strength of the building.

l_p: the hinge length (in meter)

a: the shear span length (the length of the shear force receiver) of members, the value obtained by multiplying the clear length of members and 0.5 (in meter)

R_s: the shear drift of members by the acting force on the material at safety limit strength (in radian)

R_x: the drift angle obtained by the displacement at the joint of adjacent members and the situation of each structural method (in radian)

(2) The ratio of the safety limit displacement to the height on each story specified by the previous provisions shall be not greater than 1/75 (1/30 in cases of wooden structures). If it shall be confirmed by special investigation or research that each story of the buildings continues to resist against loads and external forces at the larger displacement, this provision can be excluded.

7. The Response period for safety limit T_s stipulated in accordance with Article 82-5, item (vi), (b) shall be calculated by the following formula. When in the soil characteristics is obtained by the soil survey, the period adjustment factor calculated by the following provision can be additionally multiplied. And the precise analysis can be used when the response period for safety limit can be calculated by the methods such as characteristic value analysis based on the mass and rigidity of each part of buildings.

$$Ts = 2\pi\sqrt{Mu_s \frac{\Delta s}{Qs}}$$

Where,

Ts: the response period for safety limit (in seconds)
Mu$_s$: the effective mass of buildings calculated by the following formula (in tons)

$$Mu_s = \frac{\left(\sum m_i\ \delta s_i\right)^2}{\sum m_i\ \delta s_i^{\,2}}$$

Where,

m_i: the mass in the i-th story (in tons)

δs_i: the displacement from the basement in the i-th story in the situation which the lateral force Ps_i (in kilo Newton) corresponding the safety limit strength calculated by the following formula is acting on the i-th story (hereafter "at safety limit of the buildings) (in meters)

$$Psi = \frac{Bs_i\ m_i}{\sum_{j=1}^{N} Bs_j \cdot m_j} \cdot Qs$$

Where,

Bs_i: the distribution factor of the acceleration in the i-th story in accordance with the 8th provision

Qs: the safety limit strength of the building (in kilo-Newton)

Qs: the safety limit strength obtained by the following calculation (in kilo-Newton)

It shall be calculated as the value obtained by multiplying the minimum value of the converted base shear force coefficient ***qs_i*** at the safety limit strength obtained by the following formula and the whole weight should be multiplied.

$$qs_i = \frac{Qu_i}{Fe_i \dfrac{\sum_{j=i}^{N} Bs_j \cdot m_j}{\sum_{j=1}^{N} Bs_j \cdot m_j} \cdot \sum_{j=1}^{N} m_j \cdot g}$$

where,

qs_i: the converted base shear force coefficient at the lateral load carrying capacity in the i-th story

Qu_i: the lateral load carrying capacity in the i-th story (in kilo-Newton)

Fe_i: the value of ***Fe*** in the i-th story of the building defined by the standard (second, the Table 2) of Notification No. 1792 of 1983. When the calculation based on the influence of the eccentricity against the lateral load-carrying capacity considering the rigidity against the lateral force, strength and the arrangement of the buildings' main parts on the structural capacity, can be implemented, it shall be followed by the specific analysis.

Bs_i: the distribution factor of the acceleration in the i-th story in accordance with the 8th provision

m_i: the mass in the i-th story (in tons)

Δs: the equivalent displacement (in meter)

$$\Delta s = \frac{\sum m_i\ \delta s_i^{\,2}}{\sum m_i\ \delta s_i}$$

Where,

m_i: the mass in the i-th story (in tons)

δs_i: the displacement from the basement in the i-th story defined by the formula Mu_s (in meters)

(2) The period adjustment factor (γ) shall be calculated by the formula of Notification 1457-3, paragraph (2). In this calculation, ***Td*** and Mu_d are replaced with ***Ts*** and Mu_s.

(3) It shall be confirmed by the following methods that no rapid deterioration of lateral load carrying capacity of a building occurs at the safety limit because of brittle failure of main structural members, such as columns, beams, walls and these joints.

(i) It shall be confirmed that deformation angle of plastic hinges at each main structural member is smaller than ultimate deformation angle specified by the 6th provision when equivalent displacement of a building is 1.5 times as large as Δs specified by paragraph (1).

(ii) Calculation specified by Notification No.594-4 of 2007, item (iii) shall be conducted for main structural members without plastic hinges.

(4) are omitted.

8. The distribution factor of the acceleration in the i-th story of the building in accordance with the Article 82-5, item (vi), (c), shall be calculated based on the 4nd provision. In this calculation, table of item (iii), (c), damage limit state, ***Td***, Mu_d and bd_i are replaced with table of item (iv), (c), safety limit state, ***Ts***, Mu_s and Bs_i.

(3) Reduction rate of acceleration according to the damping of the earthquake motion

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(amended by Notification No.791 of May 31, 2016)

9. The reduction rate of acceleration according to the damping of the earthquake motion (***Fh***) provided by the Article 82-5, item (v), (c), shall be calculated by the following formula.
Provided that, ***Fh*** can be obtained by the calculation method which considers the materials corresponding to the buildings' seismic response and the influence of the buildings' damping characteristics, the precise analysis can be implemented.

$$Fh = \frac{1.5}{1 + 10h}$$

(2) In the previous formula, h shall be the value representing the damping characteristics of buildings. It is obtained by each of the following items. Provided that, the damping characteristics of members or buildings can be represented as the viscous damping coefficient which shows elasticity, the specific value can be used.

(i) The value representing the damping characteristics of buildings (***h***) shall be obtained by the following formula using the damping characteristics of each member.

$$h = \frac{\sum_{i=1}^{N} {}_m he_i \cdot {}_m W_i}{\sum_{i=1}^{N} {}_m W_i} + 0.05$$

Where,

h: the value representing the damping characteristics of the building

${}_m he_i$: the value representing the damping characteristics of each member at the safety limit, which is defined by the provision (a) regarding to the wooden-, steel-, and reinforced concrete-structural buildings and is defined by the provision (b) in other case that it is based on the structure of other buildings except for the wooden-, steel-, and reinforced concrete-structural buildings, or the deformation characteristics corresponding the strength of those members.

${}_m W_i$: the half value obtained by multiplying the displacement of each material at the safety limit and the strength of each member of the building (in kilo Newton meter)

(a) **${}_m he_i$** for members of the wooden-, steel-, and reinforced concrete-structural buildings shall be obtained by the following formula.

$${}_m he_i = \gamma_1 \left(1 - 1/\sqrt{{}_m Df_i}\right)$$

Where,

γ_1: the coefficient representing the damping characteristics corresponding the structural method of each member. See the following table,

Structural method	γ_1
Members of which the composing materials and the joints of adjacent members are connected.	0.25
Other members or bracing members sharing the compressive force of which strength is reduced by the buckling when the earthquake motion effects on	0.2

${}_m Df_i$: the value representing the level of the inelasticity of each member, shall be obtained by the following formula (it shall be 1 when it is less than 1)

$${}_m Df_i = \frac{{}_m \delta s_i}{{}_m \delta d_i}$$

Where,

${}_m \delta s_i$: the deformation of each member at the safety limit displacement

${}_m \delta d_i$: the damage limit displacement of each member

(b) **${}_m he_i$** which is based on the structure of other buildings except for the wooden-, steel-, and reinforced concrete-structural buildings, or the deformation characteristics corresponding the strength of those members shall be less than the value which is obtained by multiplying 0.8 and the equivalent viscous damping factor of the member of the buildings at the safety limit. In that case, the maximum value of ${}_m he_i$ should be obtained by applying the provision (a) and 0.25 as γ_1. The equivalent viscous damping factor shall be obtained by the following formula.

$${}_m he_i = \frac{1}{4\pi} \frac{\Delta Wi}{{}_m W_i}$$

Where,

ΔW_i: the area surrounded by the hysteresis curves with the maximum point which is the deformation of each member of the buildings at the safety limit. (in kilo Newton meter)

${}_mW_i$: the half value to be obtained by multiplying the deformation of each member of the buildings at the safety limit by the strength of each member (in kilo Newton meter)

(ii) The value representing the damping characteristics of buildings (h), can be calculated by the following formula in cases where all γ_1 as specified in the preceding provision (a) are the same in the member of which: the value representing the level of the inelasticity (${}_mDf_i$), which is specified in the preceding provision (a), is 1 or more.

$$h = \gamma_1 \, (1 - 1/\sqrt{Df}) + 0.05$$

where,

γ_1: the coefficient representing the damping characteristics corresponding the structural method of each member and the value in the table of γ_1 as specified in the preceding provision (a).

Df: the value representing the level of the inelasticity of the buildings and to be obtained by the following formula (The value shall be 1 in case where it is less than 1)

$$Df = \frac{\Delta s \, Qd}{\Delta d \, Qs}$$

Where,

Δs: the equivalent displacement at the safety limit as specified in Notification 1457-7, paragraph (1). (in meter)

Qd: the damage limit strength as specified in Notification 1457-3, paragraph (1). (in kilo Newton)

Δd: the equivalent displacement at the damage limit as specified in Notification 1457-3, paragraph (1). (in meter)

Qs: the safety strength as specified in Notification 1457-7, paragraph (1). (in kilo Newton)

(iii) The value representing the damping characteristics of buildings (***h***) shall be obtained by the following formula using the relationship between lateral force and deformation of the building.

$$h = \gamma_1 \, (1 - 1/\sqrt{Df}) + 0.05$$

γ_1: the coefficient representing the damping characteristics corresponding the structural method of each member and the value in the table of γ_1 as specified in the preceding provision (i).

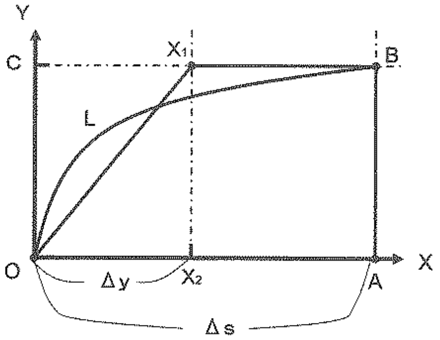
Df: the value representing the level of the inelasticity of the buildings and to be obtained by the following formula (The value shall be 1 in case where it is less than 1)

$$Df = \frac{\Delta s}{\Delta y}$$

Where,

Δs: the equivalent displacement at the safety limit as specified in Notification 1457-7, paragraph (1). (in meter)

Δy: the displacement of building at point X_2 in the following figure. (in meter)



In this figure, X-axis, Y-axis, point O, curve L, point A, B, C, X_1 and X_2 are defined by the following provisions. X-axis and Y-axis meet at right angles.

X-axis: the displacement of building. (in meter)
Y-axis: the lateral force building. (in kilo Newton)
point O: the intersection of X-axis and Y-axis
curve L: the curve representing relationship between lateral load and displacement of building (hereinafter referred to as the "characteristic curve" in this item)
point A: the point on X-axis when displacement of building is equal to **Δs**
point B: the point on the intersection of curve L and the straight line which meets X-axis at right angles and passes through point A.
point C: the point on Y-axis when lateral load of building is equal to the safety limit strength specified in Notification 1457-7, paragraph (1).
point X_1: the point on the straight line passing through point B and C and where the area of the part surrounding by straight lines OX_1, X_1B, OA and AB is equal to the area of the part surrounding by the curve L, straight lines AB and OA. Straight line BC can be replaced with the tangent of characteristic curve at the safety limit displacement in cases where displacement at each story caused by seismic forces specified by the Article 82-5, item (iii), (c) is calculated by characteristic curve.
Point X_2: the point on the intersection of straight line passing through point X1 and meeting X-axis at right angles.

(iv) The equivalent viscous damping factor (***h***) shall be calculated by the following formula in cases where the soil characteristics is obtained by the soil research.

$$h = \frac{1}{r^3}\left\{ hsw\left(\frac{Tsw}{Ts}\right)^3 + hro\left(\frac{Tro}{Ts}\right)^3 + hb \right\}$$

Where,

γ: the period adjustment factor at the safety limit as specified in Notification 1457-7, paragraph (2).

hsw: the lateral soil viscosity constant responding to the shear strain of the surface ground at the earthquake as a result of the soil survey. (In case where it is more than 0.3, it shall be 0.3.)

Tsw: the sway natural period as specified in Notification 1457-7, paragraph (2)

Ts: the response period for safety limit as specified in Notification 1457-7, paragraph (1). (in seconds)

hro: the viscous damping coefficient of soil on rotational displacement based on the shear strain of the surface ground at the earthquake as a result of the soil survey (In case where it is more than 0.15, it shall be 0.15.)

Tro: the rocking response period at the safety limit as specified in Notification 1457-7, paragraph (2). (in seconds)

Hb: the value applying the equivalent viscous damping factor of the buildings above ground in place of the equivalent viscous damping factor of the buildings obtained by any of formulas in the preceding items

(4) Acceleration amplification coefficient of the subsurface ground

Notification No.1457 of 2000

(amended by Notification No.791 of May 31, 2016)

10. Gs specified by the table of Article 82-5, item (iii), shall be calculated by the formula in the following Table 1, in cases where the ground is in the area to be applicable to the class 1 land in the table regarding to the Tc in the table 2 of Notification No. 1793-2 of the Ministry of Construction, 1980. It shall be calculated by the formula in the following Table 2, in cases where the ground is in the area to be applicable to the class 2 and 3 land.

Table 1

If $T<0.576$	$Gs=1.5$
If $0.576\leq T<0.64$	$Gs=0.864/T$
If $0.64\leq T$	$Gs=1.35$
Where, *T*: the response period of the building (in seconds)	

Table 2

If $T<0.64$	$Gs=1.5$
If $0.64\leq T<Tu$	$Gs=1.5(T/0.64)$
If $Tu<T$	$Gs=g_v$
Where, *T*: the response period of the building (in seconds) *Tu*: the value obtained by the following formula (in seconds) $Tu = 0.64(\frac{g_v}{1.5})$ g_v: the value responding to the soil classification in the following table	

the class 2 land	2.025
the class 3 land	2.7

(2) Regardless of the previous paragraph, Gs specified by the table of Article 82-5, item (vi), (c) shall be calculated by the formula in the following items (i), (ii) and (iii). In this calculation, it shall be confirmed that deformation of subsurface ground caused by liquefaction does not effect on the calculation of Gs and the inclined sloping ground, such as cliff, is not in or near the site for a building.

(i) It shall be confirmed that the site for a building has sufficient thickness and stiffness in the deep part of underground and engineering bedrock which is satisfied with the following provisions (a), (b) and (c).

(a) the wave velocity is faster than about 400 m/sec.
(b) the thickness is longer than 5m.
(c) is omitted.

(ii) ***Gs*** shall be calculated by the formula in the column (b) in the following table based on the natural response period at damage limit or the response period for safety limit in the column (a) in the following table, the predominant periods of the ground in the item (a) and the amplification factor of the ground in the item (b). In case where Gs for safety limit of the buildings is less than 0.23, it shall be 0.23. In addition, coefficient ***β*** which is related to the interaction between buildings and the ground calculated by the item (c) can be multiplied.

	(a)	(b)
(1)	If $T \leq 0.8T_2$	$Gs = Gs_2 \dfrac{T}{0.8T_2}$
(2)	If $0.8T_2 < T \leq 0.8T_1$	$Gs = \dfrac{Gs_1 - Gs_2}{0.8(T_1 - T_2)} T + Gs_2 - 0.8 \dfrac{Gs_1 - Gs_2}{0.8(T_1 - T_2)} T_2$
(3)	If $0.8T_1 < T \leq 1.2T_1$	$Gs = Gs_1$
(4)	If $1.2T_1 < T$	$Gs = \dfrac{Gs_1 - 1}{\dfrac{1}{1.2T_1} - 0.1} \cdot \dfrac{1}{T} + Gs_1 - \dfrac{Gs_1 - 1}{\dfrac{1}{1.2T_1} - 0.1} \cdot \dfrac{1}{1.2T_1}$
Where, ***T***: the natural response period at damage limit or the natural response period for safety limit of the buildings (in second) T_1: the first phase predominant period of the ground (in seconds) T_2: the second phase predominant period of the ground (in seconds) Gs_1: the amplification factor to the first phase predominant period of the ground Gs_2: the amplification factor to the second phase predominant period of the ground		

(a) The first and the second predominant periods of the ground shall be calculated by each of following formulas.

1. $T_1 = \dfrac{4\left(\sum H_i\right)^2}{\sum \sqrt{\dfrac{G_i}{\rho_i}} H_i}$

2. $T_2 = T_1/3$

Where,

T_1: the first predominant period of the ground (in seconds)
T_2: the second predominant period of the ground (in seconds)
H_i: the thickness of each layer obtained by the soil survey (in meter)
G_i: the shear stiffness of each layer calculated by the results of soil survey. The values shall be calculated based on shear strain at the earthquake.

$G0_i = \rho_i Vs_i^2$

Where,

***Vs*ᵢ**: the shear wave velocity of each layer to be obtained by the soil survey (in meter/seconds)

$\boldsymbol{\rho_i}$: the density of each layer to be obtained by the soil survey (in ton/ m^3)

(b) The amplification factor to the first phase predominant period of the ground ($\boldsymbol{Gs_1}$) and the amplification factor to the second phase predominant period ($\boldsymbol{Gs_2}$) are calculated by the following formulas, respectively.

1. $Gs_1 = \dfrac{1}{1.57h + \alpha}$

2. $Gs_2 = \dfrac{1}{4.71h + \alpha}$

Where,

$\boldsymbol{\alpha}$: the surge impedance ratio obtained by the following formula

$$\alpha = \frac{\sum \sqrt{\frac{G_i}{\rho_i}} H_i \cdot \sum \rho_i H_i}{\left(\sum H_i\right)^2} \cdot \frac{1}{\rho_B V_B}$$

Where,

$\boldsymbol{\rho_B}$: the density of the engineering bedrock obtained by the soil survey (in ton/m^3)

$\boldsymbol{V_B}$: the shear wave velocity of the engineering bedrock obtained by the soil survey (in meter/seconds)

$\boldsymbol{h}$: the value calculated by the following formula to represent the energy absorbency by the subsurface ground at the earthquake (It shall be 0.05 when it is less than 0.05.)

$$h = \frac{\sum h_i w_i}{\sum w_i}$$

Where,

$\boldsymbol{h_i}$: the value based on the shear deformation of subsurface ground caused by the earthquake to represent the damping factor of each subsurface layer at the earthquake

$\boldsymbol{w_i}$: the value calculated by the following formula to represent the maximum elastic deformation energy of each subsurface layer at the earthquake

$$w_i = \frac{G_i}{2H_i}(u_i - u_{i-1})^2$$

Where,

$\boldsymbol{u_i}$: the relative displacement from each layer's top from the engineering bedrock at the earthquake (in meter)

(c) The factor related to the interaction between buildings and the subsurface ground ($\boldsymbol{\beta}$) shall be calculated by the following formula. $\boldsymbol{\beta}$ shall be 0.75 in case where it is less than 0.75.

$$\beta = \frac{K_{hb}\left\{1-\left(1-\frac{1}{Gs}\right)\frac{D_e}{\sum H_i}\right\}+K_{he}}{K_{hb}+K_{he}}$$

Where,

K_{hb}: the lateral soil spring constant on the base of the underground part of the building, which is obtained by the soil survey (in kilo Newton/meter)

Gs: the value of **Gs** as specified in the item (ii)

D_e: the depth from the ground surface to the basal surface (in meters)

H_i: the thickness of each ground layer as specified in (a) (in meters)

K_{he}: the lateral soil spring constant on the lateral of the underground part of the building, which is obtained by the soil survey (in kilo Newton/meter)

(iii) is omitted.

7.3.3 Other calculations in CARLS

Notification No.1457-11 of 2000 stipulates the methods for the roofing materials, etc. Calculations equivalent to those for allowable unit stress, etc., are used for wind pressure. In addition, the following structural calculations are required in relation to earthquakes.

- Stresses acting on attachments for the roofing materials, due to acceleration acting on the story where the roofing materials are attached, shall not exceed the temporary allowable unit stress level.
- Stresses acting on attachments for exterior materials, due to acceleration acting on the bottom and top parts of the attachments, shall not exceed the temporary allowable unit stress level.
- Stresses acting on the attachments for exterior materials, etc., due to inter-story deformation, shall not exceed the temporary allowable unit stress level.

Notification No.1457-11 of 2000 also stipulates the methods for specific ceilings, fall of which causes serious injure.

- Strength and stiffness of members, which compose ceiling surface, shall be satisfied with the criteria.
- Stresses acting on ceilings, due to horizontal and vertical accelerations acting on the upper structure, shall not exceed the allowable unit stress level.
- Gap between ceilings and structural elements shall be satisfied with the criteria calculated by the natural periods of the ceilings, hanging length and so on.