Time History Response Analysis of High Rise Building and Performance Evaluation

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Article 4: Evaluation Standards

4.1 Safety under long-term loads
4.2 Safety under snow loads
4.3 Safety under wind pressures
4.4 Safety under seismic force
4.5 Combination of loads
4.6 Usability under long-term loads
4.7 Safety of exterior finishing materials, etc

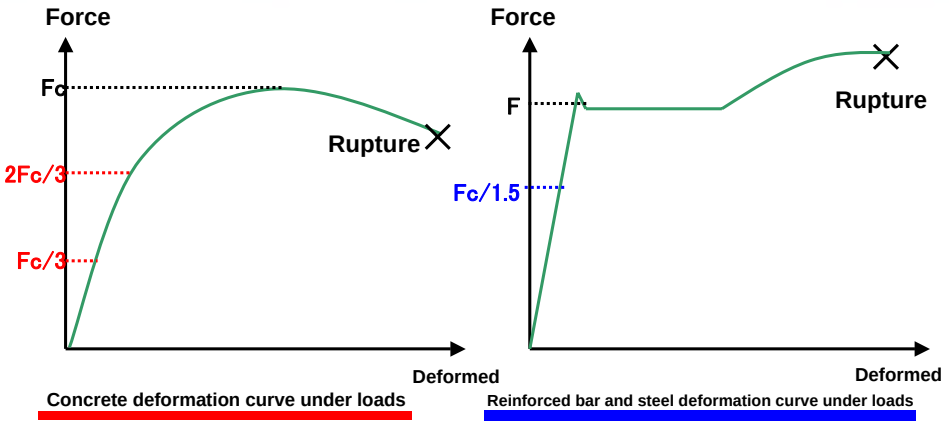
4.1 Safety under long-term loads

(1)It must be confirmed that there will be no damage to elements necessary for structural resistance of the building as a result of loads imposed on parts of the building under actual conditions, including dead loads and live loads, or as a result of external forces (such as snow loads in regions affected by heavy snowfall, earth pressure, loads associated with temperature changes, and loads resulting from the shrinkage, etc., of materials).

(2)It must be confirmed that damage will not occur, using the allowable stress design. In the case of concrete structures, it must be confirmed that there will be no cracking with the potential to reduce durability.

Confirm that long-term loads are within the long-term allowable stress

What is allowable stress design?



	Long-term allowable stress	Short-term allowable stress
Concrete	1/3 Fc	2/3Fc
Steel	F/1.5	F
Reinforced bar	F/1.5	F

4.2 Safety under snow loads

(1)Structural calculations concerning snow loads imposed on the building must be carried out using the method stipulated in Item 2 of Ministry of Construction Notification #1461 of 2000 (hereinafter referred to as “the Notification”).

(2)It must be confirmed that the building will not suffer damage under the prescribed loads, using the allowable stress design.

(3)It must be confirmed that the building will not collapse under the prescribed loads, through confirmation that the forces acting on individual parts will not exceed the level at which plasticization will occur in part of the members, and that a state of mechanism will not occur even partially.

Confirm that snow loads are within the short-term allowable stress

4.3 Safety under wind pressures

(1)Structural calculations concerning wind pressures acting on the building must be carried out.

(2)It must be confirmed that the building will not suffer damage under the prescribed loads, through confirmation that allowable deformation will not be exceeded in principal parts essential to the structural capacity of the building.

(3) It must be confirmed that the building will not collapse under the prescribed loads, through confirmation that parts essential to the structural capacity of the building will remain within the range of elastic behavior.

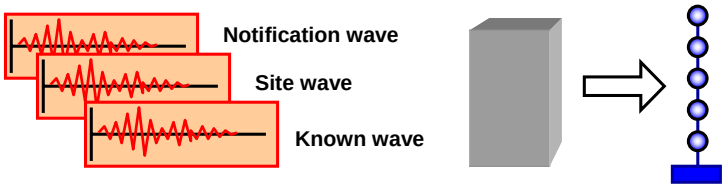
(4)If the height of the building is 100m or greater, and if the aspect ratio (height/apparent width on the shorter side) is 3 or greater, vibration and torsional vibration must be given appropriate consideration in relation to Items (2) and (3) above.

Wind loads
Confirm that level 1 wind is within the short-term allowable stress
Confirm that level 2 wind is within the elastic range
Confirm that vibration and torsional vibration are appropriate

4.4 Safety under seismic force

4.4.1 Setting of earthquake motion in horizontal direction

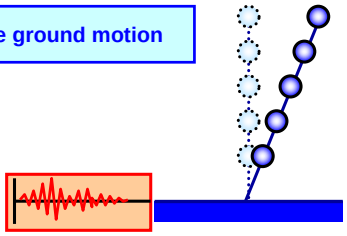
4.4.2 Configuration of vibration model of building for use in response analysis



4.4.3 Calculation of responses to earthquake ground motion

Equation of motion

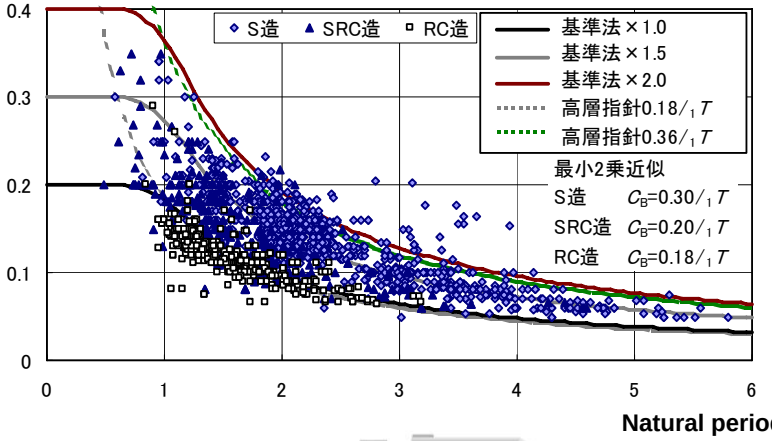
$$[M]\{\ddot{y}\}+[C]\{\dot{y}\}+[K]\{y\}=-[M]\{\ddot{y}_0\}$$



4.4.4 Evaluation criteria

Base shear coefficient for high rise building

base shear coefficient



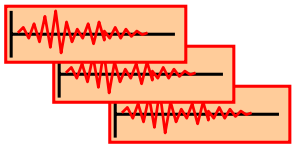
Natural period of high rise building and base shear coefficient

4.4 Safety under seismic force

4.4.1 Setting of earthquake motion in horizontal direction

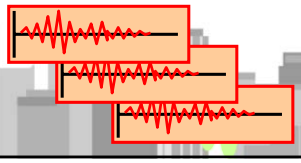
- (1) Notification wave
- (2) Site wave

→ Use at least three waves



- (3) Known wave

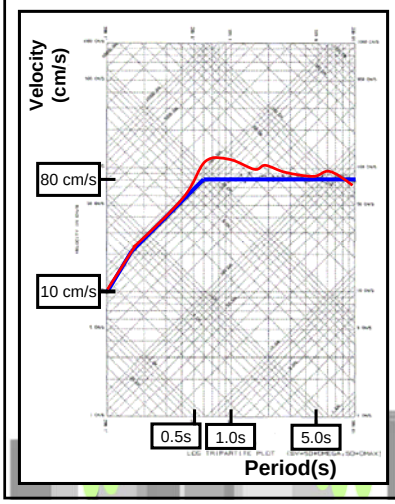
→ Use at least three waves



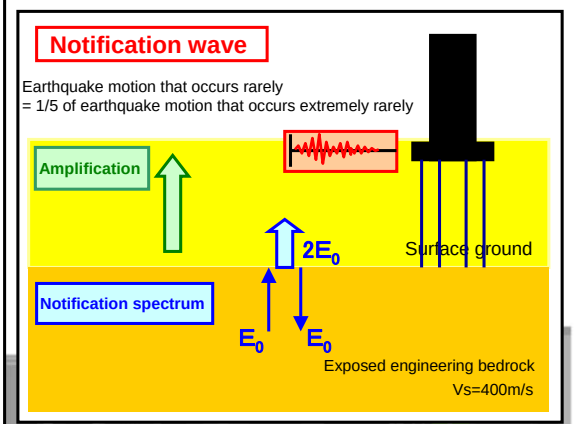
4.4 Safety under seismic force

4.4.1 Setting of earthquake motion in horizontal direction → **(1) Notification wave**

The design earthquake motion consists of seismic waves having the acceleration response spectrum of the exposed engineering bedrock, considering appropriate wave-amplification in the subsurface of the building (hereinafter referred to as "the Notification waves").



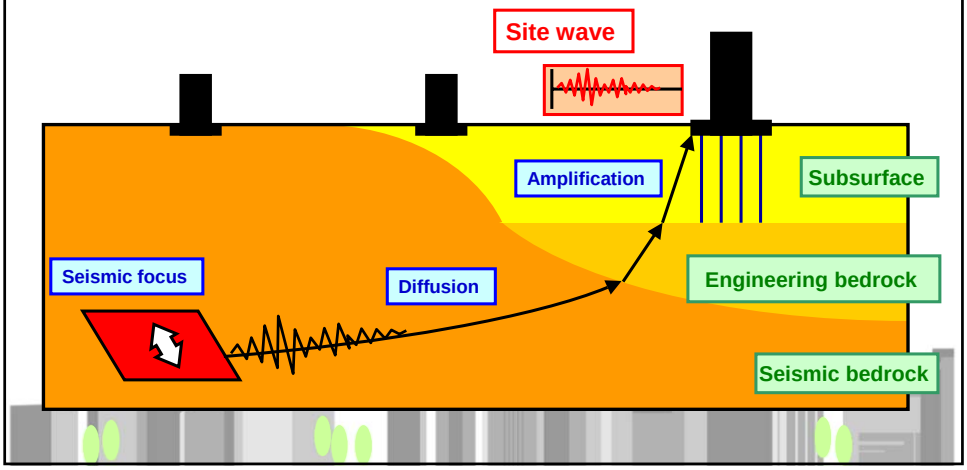
Amplified Notification spectrum
Notification spectrum



4.4 Safety under seismic force

4.4.1 Setting of earthquake motion in horizontal direction → **(2) Site wave**

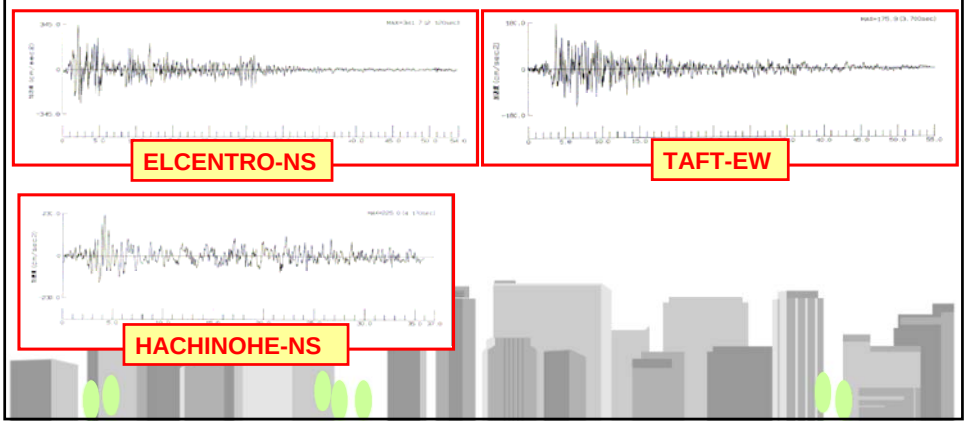
Simulated seismic wave at construction site based on active fault distribution in the area around the building site, the fault rupture model, historical earthquake activity, bedrock structure and other factors (hereinafter referred to as the "site wave")



4.4 Safety under seismic force

4.4.1 Setting of earthquake motion in horizontal direction → **(3) Known wave**

At least three waves must be selected from representative recorded earthquake motions in the past, with appropriate consideration for the characteristics of the site and the building, and waves adjusted with maximum velocity amplitudes of 25cm/sec. and 50cm/sec. must be used to represent earthquake motion that rarely occurs and occurs extremely rarely, respectively.



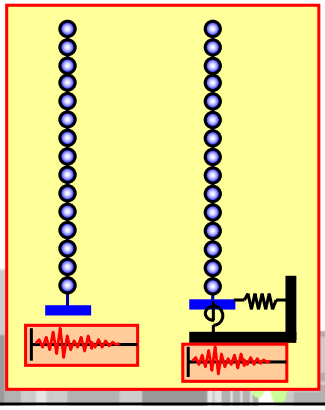
4.4 Safety under seismic force

4.4.2 Configuration of vibration model of building for use in response analysis

(1) The vibration model of building must be configured to allow appropriate monitoring of forces and deformation of the building, according to the adopted structural system and vibration properties of the building.

(2) If the foundation structure of the building is such that dynamic soil-structure interaction is estimated to have a substantial influence on vibration properties, the vibration model must be configured to reflect the interaction effect appropriately.

Put into model



4.4 Safety under seismic force

4.4.2 Configuration of vibration model of building for use in response analysis

(3) The restoring force properties and damping properties of the vibration model should appropriately reflect the structural system and vibration properties of the building.

(4)If the restoring force properties have been configured for individual stories, the properties must be decided based on the results of static elastic-plastic analyses or an equivalent method that is based on appropriate assumptions concerning the distribution of seismic force on each level and gives appropriate consideration to the elastic-plastic restoring force properties of each member.

Equation of motion for use in seismic response analysis

$$[M]\{\ddot{y}\}+[C]\{\dot{y}\}+[K]\{y\}=-[M]\{\ddot{y}_0\}$$

Acceleration | Speed | Displacement | Seismic wave

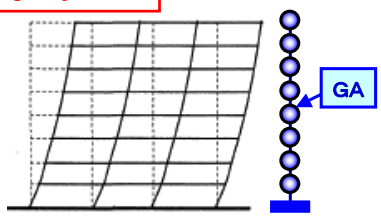
Mass [M] — Appropriately set depending on the use of a building

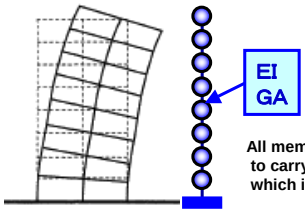
Damping [C] — **Example**: Reinforced concrete structured building h1=0.03%, steel structured building h1=0.02%

4.4 Safety under seismic force

4.4.2 Configuration of vibration model of building for use in response analysis

Rigidity ［K］

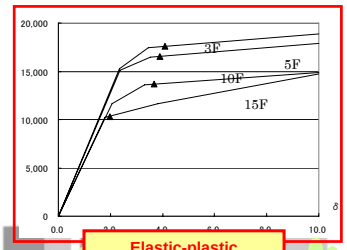




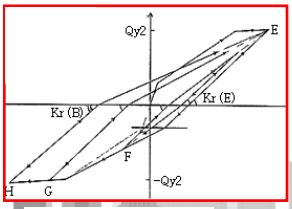
All members are put into model to carry out settlement analysis which is also available

Wide building

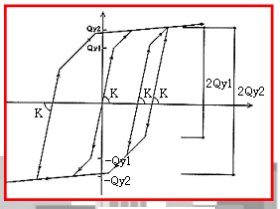
Long building



Elastic-plastic analysis results



Reinforced concrete structure



Restoring force properties

Steel structure

4.4 Safety under seismic force

4.4.4 Evaluation criteria

(1) Damage limit against earthquake motion that occurs rarely

(i) Inter- story drift angle not exceeding 1/200
(ii) Within allowable stress

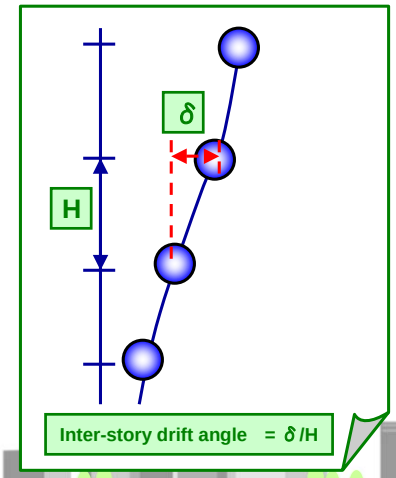
(2) Safety limit against earthquake motion that occurs extremely rarely

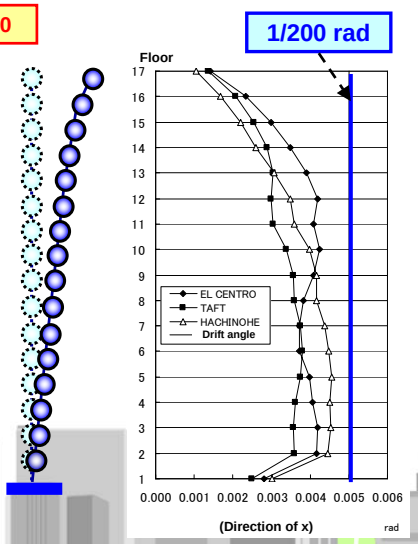
(i) Inter-story drift angle not exceeding 1/100
(ii) Ductility factor for each floor not exceeding 2.0
(iii) Member ductility factor not exceeding 4.0

4.4 Safety under seismic force

4.4.4 Evaluation criteria → **(1) Damage limit against earthquake motion that occurs rarely**

(i) Inter-story drift angle not exceeding 1/200



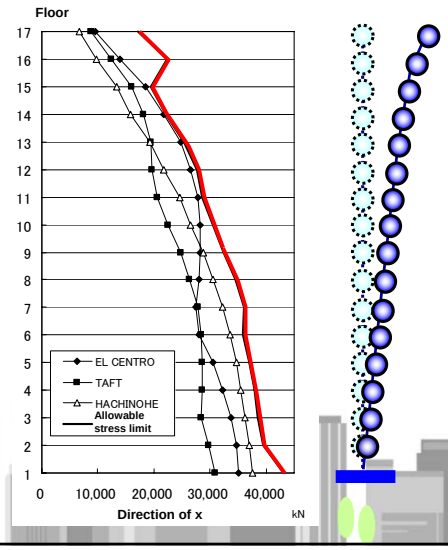


4.4 Safety under seismic force

4.4.4 Evaluation criteria → **(1) Damage limit against earthquake motion that occurs rarely**

(ii) Within allowable stress

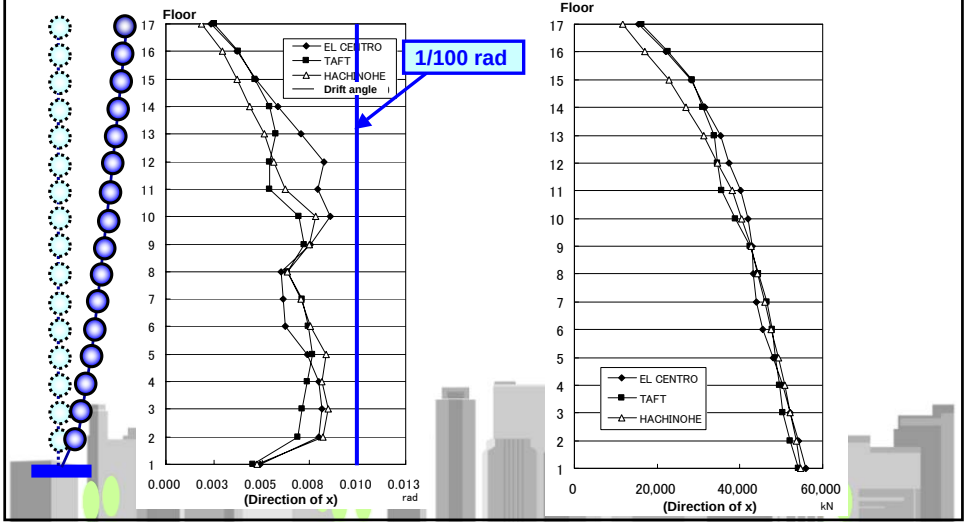
It must be confirmed that stress acting on elements necessary for structural resistance do not exceed short-term allowable stress, and that there will be no remarkable residual cracking or deformation after an earthquake.



4.4 Safety under seismic force

4.4.4 Evaluation criteria → **(2) Safety limit against earthquake motion that occurs extremely rarely**

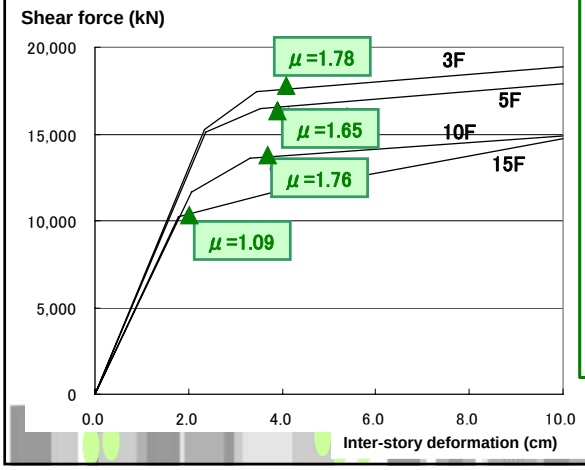
(i) Inter-story drift angle not exceeding 1/100

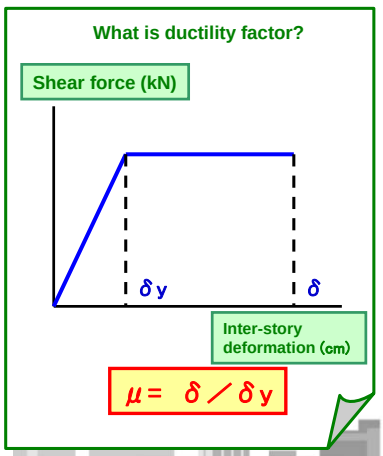


4.4 Safety under seismic force

4.4.4 Evaluation criteria → **(2) Safety limit against earthquake motion that occurs extremely rarely**

(ii) Ductility factor for each floor not exceeding 2.0
(iii) Member ductility factor not exceeding 4.0





4.4 Safety under seismic force

4.4.3 Calculation of responses to earthquake ground motion

(1)The response values of building must be determined by solving equations of motion for the vibration model under earthquake motions, using appropriate methods.

(2)Responses must be determined with earthquake motion applied separately along each of two perpendicular axes. Responses when earthquake motion is applied simultaneously along two axes or along an axis at an angle of 45 degrees to the main axis must also have been determined using an appropriate method.

(3)The effect of earthquake motion in a vertical direction must be evaluated appropriately, taking into account its simultaneity with horizontal earthquake motion, and also taking into account the size and shape of the building.

(4)Where the size and shape of a building are such that it may be affected by phase differences in input earthquake motion, as in the case of buildings with large horizontal dimensions, this effect must be taken into account, using an appropriate method.

(5)The effect of horizontal deformation on vertical loads must be taken into account appropriately.

4.5 Combination of loads

When considering safety under snow loads, wind pressure or seismic forces, appropriate consideration must be given to the combination of loads and external forces as defined in 4.1.

4.6 Usability under long-term loads

It must be confirmed, using the method stipulated in Article 82 Item 4 of the Order, or an equivalent method, that deformation of, or vibration in, structural members that are important to structural capacity due to loads or external forces occurring under actual conditions as defined in 4.1 will not cause a hindrance to the use of the building.

Confirm that flexure against long-term loads does not exceed 1/250
(In case of RC the creep coefficient 8, 16 must be taken into consideration)

4.7 Safety of exterior finishing materials, etc.

It must be confirmed, using the methods stipulated in ① and ② below, that roofing materials, exterior finishing materials, and curtain walls facing the outside are safe in terms of structural capacity under wind pressure, earthquakes or other vibrations, and impacts.

①. It must be confirmed by means of response values obtained using structural calculations based on the methods stated in 4.3 and 4.4 that damage will not occur as a result of strong winds or earthquake motion that occurs rarely, as defined in Item 3(a) of the Notification, and that materials will not detach and fall as a result of strong winds or earthquake motion that occurs rarely, as defined in Item 3(b) of the Notification.

②. Safety in terms of structural capacity under wind pressure must be confirmed using the method stipulated in Ministry of Construction Notification #1458 of 2000.

Confirm that curtain walls do not fall off from inter-story drift angle at earthquake
Confirm that glass does not collapse against wind

Summary

4.1 Safety under long-term loads

Confirm that long-term loads are within the long-term allowable stress

4.2 Safety under snow loads

Confirm that snow loads are within the short-term allowable stress

4.3 Safety under wind pressures

Confirm that level 1 wind is within the short-term allowable stress
Confirm that level 2 wind is within the elastic range

Summary

4.4 Safety under seismic force

(1) Damage limit against earthquake motion that occurs rarely

(i) Inter-story drift angle not exceeding 1/200
(ii) Within allowable stress

(2) Safety limit against earthquake motion that occurs extremely rarely

(i) Inter-story drift angle not exceeding 1/100
(ii) Ductility factor for each floor not exceeding 2.0
(iii) Member ductility factor not exceeding 4.0

4.6 Usability under long-term loads

Confirm that flexure against long-term loads does not exceed 1/250

4.7 Safety of exterior finishing materials, etc.

Confirm that curtain walls do not fall off from inter-story drift angle at earthquake
Confirm that glass does not collapse against wind