

Seismic Design Criteria of Water Supply Facilities

Seismic performances, basic items of seismic design of water supply facilities in Japan, are stipulated by “Ministerial Ordinance Defining Technical Criteria of Water Supply Facilities”, an ordinance relevant to the Waterworks Law. Since this ordinance does not have concrete descriptions on seismic design, however, “Guideline to and Explanation of Seismic Construction Method of Water Supply Facilities” published and revised based on damages by earthquakes by the Japan Water Works Association (JWWA) is used for practical work.

This article, in accordance with the above guideline, introduces concept of seismic design of water supply facilities.

Organization of “Guideline to and Explanation of Seismic Construction Method of Water Supply Facilities - 2009”

Consists of three separate volumes: I. General and Explanation of General, II. Details, and III. Examples.

Contents

I General

Chapter 1 General rules

- 1.1 Range of applications
- 1.2 Definition of terms

Chapter 2 Basic policy on seismic design

- 2.1 Basic concept of earthquake disaster prevention measures of water supply facilities
- 2.2 Earthquake disaster prevention measures from viewpoints of water supply systems
- 2.3 Basic policy on seismic design
- 2.4 Design seismic ground motion
- 2.5 Principle of verification of seismic performance

Chapter 3 Seismic calculation method

- 3.1 Design conditions of seismic calculation method
- 3.2 Verification of seismic performance of buried pipelines
- 3.3 Seismic calculation method of shafts, covered conduits, utility conduits, and shield tunnels
- 3.4 Seismic calculation method of distribution reservoirs and similar structures
- 3.5 Seismic calculation method of water pipe bridges and aqueduct bridges
- 3.6 Verification of seismic performance of architectural structures of water supply facilities

Explanation of general

Explanation of ministerial ordinances stipulating technical criteria of water supply facilities, rational study of cases of seismic design of water supply facilities by economy verification, setting of design seismic ground motion used for static analysis, consideration of recent large-scale seismic ground motion, examples of input seismic ground motion used for dynamic analysis, seismic ground motion prediction techniques assuming earthquake source fault, and seismic calculation method of buried pipelines

II Details

Chapter 4 Details of seismic construction methods, measures, and structures

- 4.1 Concrete and steel structures
- 4.2 Pipeline structures and appendages

- 4.3 Architectural structures
- 4.4 Mechanical and electrical instrumentation facilities
- 4.5 Seismic diagnosis and reinforcement

Appendix

III. Examples

- Examples of rational seismic design by economy verification (work to make pipelines resistant to earthquake, design of new distribution reservoirs)
- Examples of seismic design of buried pipelines, shafts, shield tunnels, distribution reservoirs and similar structures, ground-work tanks (pre-stressed concrete (PC) structure, steel structure), water pipe bridges (superstructures and substructures), structures for compound water supply usage

Main descriptions Excerpts from “I General” (Chapter numbers are the same as those of the text.)
 1 General rules

This Guideline describes the general criteria of seismic design and construction work of water supply facilities.

In principle, this Guideline is mainly aimed at making the structure of a water supply facility resistant to earthquakes and is applied to seismic design and construction work of water supply facilities to be newly installed. Because it is in general necessary to keep in good conditions water supply facilities having appropriate seismic performance in water supply projects, this Guideline can also be applied to seismic calculation of existing water supply facilities if there are no other clear provisions.

This Guideline employs a performance design approach as its design concept. Figure 1-1 shows a hierarchical model of design.

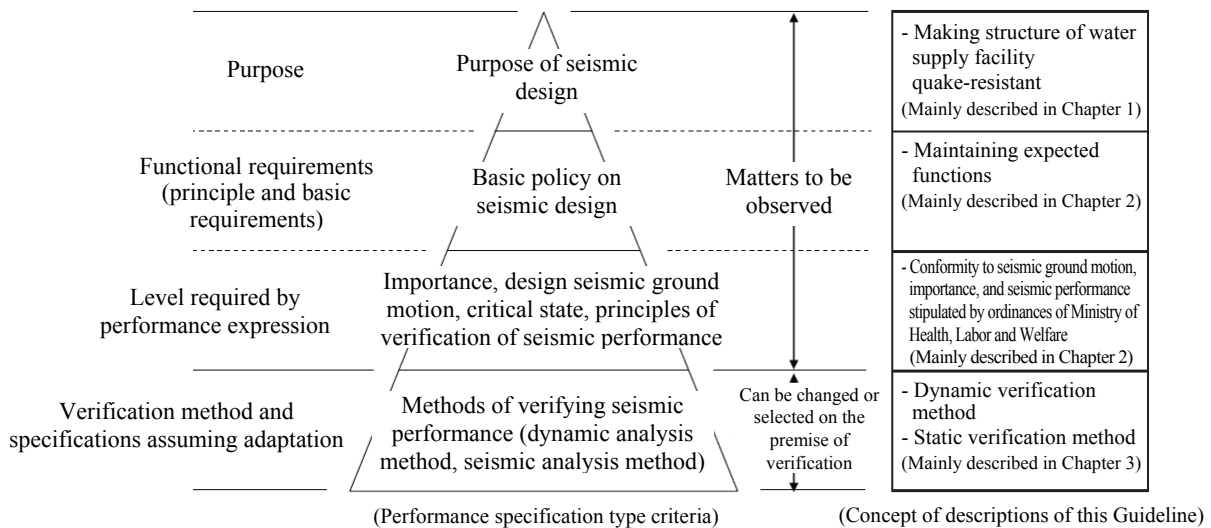


Figure 1.1 Hierarchical model of performance specification type design

2 Basic policy on seismic design

2.1 Basic concept of earthquake disaster prevention measures of water supply facilities

2.1.1 General

Water supply facilities are required, as a basic mission, to secure constant water supply in case of a disaster such as an earthquake, as well as at normal time. In preparing a water supply facility, the structure of individual water supply facilities constituting waterworks shall be made resistant to earthquakes and, at the same time, the water supply facility shall be able to be quickly recover from damages and functional

disorders it incurred. As an overall water supply facility, a facility that secures water supply shall be prepared and, at the same time, attention must be paid to making and establishing plans to temporarily supply water and restore damaged facilities after occurrence of an earthquake.

2.1.2 Planning, design, construction work

In planning, designing, and constructing a water supply facility, adequate consideration shall be given to influences of soil transformation, liquefaction, lateral flow that may occur, while ensuring that the structure is safely protected from actions caused by a seismic ground motion, in accordance with the importance of the water supply facility. Even if a facility is damaged by an earthquake, efforts shall be made to promptly restore constant water supply as a water supply system as a whole.

2.2 Earthquake disaster prevention measures from viewpoints of water supply systems

2.2.1 Assessment of seismic performance of water supply system

The earthquake resistance of a water supply system shall be rationally improved, anticipating an earthquake that may occur in the region where the system is installed, determining a goal of making the water supply system resistant to that earthquake, and based on the characteristics of individual water supply systems.

To make the facility and pipelines structurally resistant to earthquake, the earthquake resistance of the water supply system shall be assessed, and the priority of facility and pipelines important and indispensable for attaining a goal of making them earthquake resistant shall be determined. Based on these assessment and priority, seismic plans and project plans shall be made.

To assess earthquake resistance, damages shall be first anticipated based on “anticipation of a subject earthquake” and then “assessment of facility and pipelines”, components of a water supply system, shall be made. Based on their result, “assessment of earthquake resistance of a water supply system” shall be performed. In assessing a system, it shall be checked whether the targeted earthquake resistance is achieved. If not, a study shall be conducted as to which facility or pipeline should be made more quake-resistant.

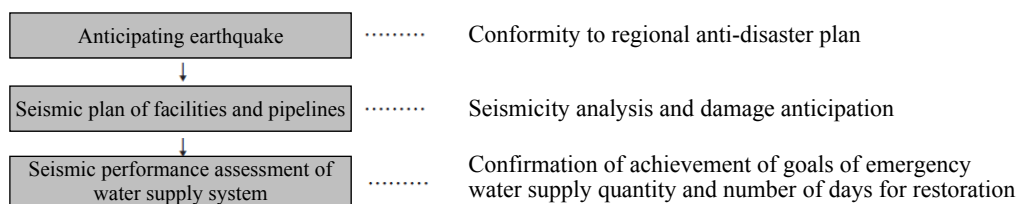


Figure 2.2.1 Basic procedure for seismic assessment of water supply system

2.2.2 Total earthquake disaster prevention measures

To conduct a comprehensive study on earthquake disaster prevention measures of a water supply system, it is important to minimize damages by improving the earthquake resistance of the overall water supply system, as well as making individual facilities quake-resistant. In taking earthquake disaster prevention measures, therefore, the following points shall be considered:

1. As earthquake disaster prevention measures for facility structures, generation of damages shall be suppressed and influences shall be limited as much as possible.
2. As comprehensive measures anticipating disasters, efforts shall be made to quickly restore and provide emergency water supply.
3. In anticipating damages resulting from an earthquake, indirect influences of the earthquake on the

water supply, social damages resulting from damages to the water supply system, and secondary disaster caused by damages to the water supply facility from the earthquake shall be considered.

2.2.3 Moving forward earthquake resistance project

It is desirable to make an earthquake resistance plan and a project execution plan that indicates the concrete project content of the earthquake resistance plan, by making a plan which indicates the basic policy of measures against earthquakes, when performing an earthquake resistance project. At that time, the following points shall be studied:

1. Project priority
2. Conformity to other facility preparation project
3. Annual project content
4. Water supply control and management during seismic construction

2.3 Basic policy on seismic design

2.3.1 General

Water supply facilities shall be designed to secure the seismic performance each of the water supply facilities should hold in case of an earthquake in accordance with the level of design seismic ground motion and the importance of the facilities. For seismic design, the structural characteristics and the ground characteristics of the surrounding shall be considered and a seismic design method suitable to them shall be used.

2.3.2 Principles of seismic design

1. The following two levels of design seismic ground motions shall be considered for seismic design of water supply facilities:
 - 1) Level-1 seismic ground motion
Of the seismic ground motions anticipated to occur at installation site of a water supply facility, the one with the highest possibility of occurrence during service period of the facility
 - 2) Level-2 seismic ground motion
Of the seismic ground motions anticipated to occur at installation site of a water supply facility, the one with an intensity of the largest scale
2. The importance of a water supply facility is classified into three types of ranks: rank A1, rank A2, and rank B.
3. The seismic performances of a water supply facility are as follows:
 - 1) Seismic performance 1
Performance not to damage healthy functions due to an earthquake
 - 2) Seismic performance 2
Performance not to seriously affect functions by minimizing damages caused by an earthquake and minimize recovery required after the earthquake
 - 3) Seismic performance 3
Performance to minimize damages caused by an earthquake and, though recovery is needed after the earthquake, not to seriously affect the functions
4. Seismic damage is performed on water supply facilities as follows in accordance with the rank of importance (see 2.3.3) and level of design seismic ground motion.
 - 1) A water supply facility of rank A1 shall be designed to secure seismic performance 1 against seismic ground motion of level 1 and seismic performance 2 against seismic ground motion of level 2.
 - 2) A water supply facility of rank A2 shall be designed to secure seismic performance 1 against

seismic ground motion of level 1 and seismic performance 3 against seismic ground motion of level 2.

- 3) A water supply facility of rank B shall be designed to secure, in principle, seismic performance 2 against a seismic ground motion of level 1.

Table 2.3.1 Seismic performance to be held by importance of facilities (level-1 seismic ground motion)

Classification of importance	Seismic performance 1	Seismic performance 2	Seismic performance 3
Rank-A1 water supply facility	○	-	-
Rank-A2 water supply facility	○	-	-
Rank-B water supply facility	-	○	△

△: Applied to water supply facilities of rank B which may be structurally damaged partially but can restore their functions by repair, etc.

Table 2.3.2 Seismic performance to be held by importance of facilities (level-2 seismic ground motion)

Classification of importance	Seismic performance 1	Seismic performance 2	Seismic performance 3
Rank-A1 water supply facility	-	○	-
Rank-A2 water supply facility	-	-	○
Rank-B water supply facility	-	-	*

*: Although the seismic performance to be held is not stipulated in this table, an ordinance of the Ministry of Health, Labor and Welfare stipulates “consideration shall be given so that quick recovery can be made, minimizing the influences on supply of water”.

2.3.3 Classification of importance of water supply facilities

Basically, the importance of water supply facilities is classified as shown in Table 2.3.3.

Table 2.3.3 Classification of importance of water supply facilities

Classification of importance of water supply facilities	Subject water supply facility
Water supply facility of rank A1	Of the important water supply facilities shown in Table 2.3.4, water supply facilities other than those of rank A2
Water supply facility of rank A2	Of the important water supply facilities shown in Table 2.3.4, water supply facilities that satisfy both the following 1) and 2): 1) Water supply facility with alternative facility 2) Water supply facility with a low possibility of incurring serious secondary disaster if damaged
Water supply facility of rank B	Water supply facilities other than those of ranks A1 and A2 above

Table 2.3.4 Important water supply facilities

Important water supply facilities	(1) Water intake facility, water storage facility, water conveyance facility, water treatment facility, and water transmission facility (2) Of water distribution facilities, those which have a high probability of incurring serious secondary damages if damaged (3) Of water distribution facilities, facilities other than (2) and fall under the following: (i) Distribution main (of water distributing pipe, those that do not have a branch of water supply pipe. The same applies to the following.) (ii) Pump station connected to distribution main (iii) Distribution reservoir connected to distribution main (equipment that adjusts capacity of distribution reservoir and for water distribution. The same applies to the following.) (iv) Distribution reservoir with maximum capacity for water supply without distribution main
-----------------------------------	---

2.3.4 Procedure of seismic design

Basically, seismic design of water supply facilities is performed in the following procedure:

1. Selection of construction site
2. Setting seismic performance in accordance with the importance of the water supply facility
3. Geotechnical investigation at construction site
4. Selection of structural form and determination of facility specifications
5. Seismic calculation
6. Verification of seismic performance

Economy verification shown in Figure 2.3.1 Flow of seismic design is a technique to set an earthquake resistance level taking into consideration economy and rationality from the viewpoint of total cost including the expenses required for installing a new water supply facility and the amount of damage caused by an earthquake.

Economy verification shall set a scale of the most rational design seismic intensity, using the total cost of construction expense, maintenance and repair expenses, and social damages as parameters, while sustaining the function stipulated by the ordinance of the Ministry of Health, Labor and Welfare against a seismic ground motion of level 1 (important water supply facilities shall not lose a healthy function and other facilities shall have little damage and not have its function seriously affected).

Table 2.3.5 Index for implementing economy verification

Effect of economy verification	Concrete example of water supply facilities for which implementing economy verification is considered significant
I. Those which are considered to have a high effect of implementation of economy verification	Of important facilities in a region where there is a high risk of earthquake, those that have serious social impacts (Example) 1. Distribution reservoir with a capacity of several 10,000 m ³ or more 2. Water treatment facility with a purification capability of several 100,000 m ³ or more 3. Important trunk pipeline
II. Other than I	Other than above

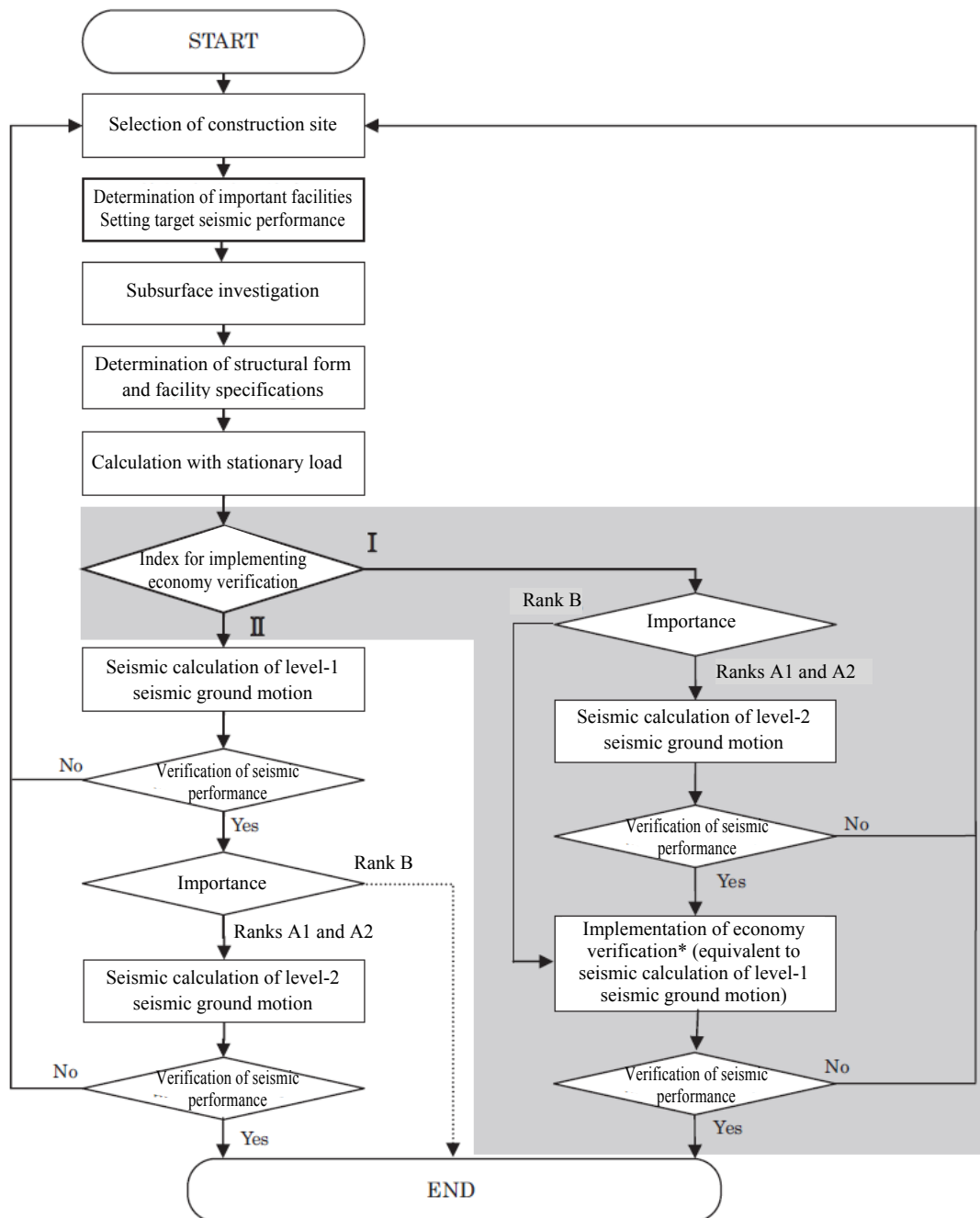


Figure 2.3.1 Flow of seismic design

* Seismic performance is basically measured in elastic limit (no structural damages) for economy verification and input seismic ground motion is set by cost effectiveness as a parameter.

2.3.5 Influences of earthquake to be considered in seismic design

The following influences of earthquakes shall be considered in seismic design of a water supply facility:

1. Influence of fault displacement
2. Influence of seismic ground motion (seismic action)
3. Influence of sloshing
4. Influence of soil liquefaction and lateral flow
5. Influence of slides, etc. on slope

2.4 Design seismic ground motion

1. Seismic ground motions of levels 1 and 2 shall be appropriately set, taking into consideration, in principle, seismic activities around the construction site, source characteristics of an earthquake, propagation and amplification characteristics of a seismic ground motion from an epicenter to the construction site.
2. Seismic ground motions of levels 1 and 2 shall be set on a ground surface or engineering bedrock.
3. Seismic ground motions of levels 1 and 2 shall be expressed as a time-history acceleration waveform or response spectrum.

Principles of setting design seismic ground motion

Seismic ground motions of levels 1 and 2 shall be appropriately set, taking into consideration, in principle, seismic activities around the construction site, source characteristics of an earthquake, propagation and amplification characteristics of seismic ground motion from an epicenter to the construction site. If it is difficult, however, an existing strong-motion earthquake record may be used.

Table 2.4.1 Method of setting seismic ground motion of level 1

Setting method	Design seismic ground motion used for dynamic analysis	Design seismic ground motion used for static analysis
To set by using conventional method	To perform linear analysis, use the ground conditions at the construction site and time-history acceleration waveform described in “Setting design seismic ground motion used for static analysis” in “Explanation of General” and to which a spectrum is fit. To consider the non-linearity of structure components, however, use an observation record under ground conditions similar to those at the site and with a time-history acceleration waveform that can be regarded as an equivalent to the design seismic intensity of “Setting design seismic ground motion used for static analysis” in “Explanation of General”.	Use the ground conditions at the construction site and the specific frequency of a structure and use the design seismic intensity of “Setting design seismic ground motion used for static analysis” in “Explanation of General”.
To set by using economy verification	(1) Set plural analysis models (design cross sections) by static analysis, using several design seismic intensities. (2) Of the seismic ground motions anticipated by seismic ground motion assessment assuming an earthquake source fault or of the earthquakes observed under the ground conditions similar to those at the construction site, extract earthquakes of different scales from those recorded an intensity of less than 5 to 6 or more on the Japanese seismic scale. (3) Perform dynamic analysis by inputting the time-history acceleration waveform of plural seismic ground motions extracted in (2) to the analysis model set in (1), and perform economy verification, using construction expenses and damages from an earthquake as indicators. (4) Using the result of (3), determine the elastic limit at which the total cost is minimized. Based on that, decide on design seismic intensity of a seismic ground motion of level 1.	(1) Set plural analysis models (design cross sections) by static analysis, using several design seismic intensities. (2) Of the seismic ground motions anticipated by seismic ground motion assessment assuming an earthquake source fault or of the earthquakes observed under the ground conditions similar to those at the construction site, extract earthquakes of different scales from those recorded an intensity of less than 5 to 6 or more on the Japanese seismic scale. (3) Perform static analysis by inputting the response spectrum of plural seismic ground motions extracted in (2) to the analysis model set in (1), and perform economy verification, using construction expenses and damages from an earthquake as indicators. (4) Using the result of (3), determine the elastic limit at which the total cost is minimized. Based on that, decide on design seismic intensity of a seismic ground motion of level 1.

* Design seismic intensity of a seismic ground motion of level 1 stipulated in “Setting design seismic ground motion used for static analysis” in “Explanation of General” was created for each type of ground based on a record of the past earthquakes (in conformance with Road Bridge Specifications).

Table 2.4.2 Method of setting seismic ground motion of level 2

Setting method		Design seismic ground motion used for dynamic analysis	Design seismic ground motion used for static analysis
Method 1	Assess a seismic ground motion, assuming an earthquake source fault, and use a seismic ground motion at the site.	Use the ground surface resulting from the seismic ground motion assessment, or time-history acceleration waveform or response spectrum on engineering bedrock.	Use the ground surface resulting from the seismic ground motion assessment or response spectrum on engineering bedrock.
Method 2	Use an anticipated seismic ground motion such as of a regional disaster prevention plan.	Use the ground surface of an anticipated seismic ground motion or time-history acceleration waveform on engineering bedrock.	Use the ground surface of an anticipated seismic ground motion or response spectrum on engineering bedrock.
Method 3	Use a record of an earthquake of an intensity of 6 or more to 7 on the Japanese seismic scale of the strong earthquakes recorded on a ground surface under ground conditions (ground type) similar to the site.	Use a time-history acceleration waveform of a record of strong earthquakes.	Use a response spectrum of a record of strong earthquakes.
Method 4	Design seismic intensity and design response spectrum set based on the record of observation of the earthquake that occurred in the Great Hanshin-Awaji Earthquake.	Use the design response spectrum in “Explanation of General (part re-posted to Guideline of 1997) or time-history waveform satisfying it.	Use the design response spectrum, etc., in “Explanation of General (part re-posted to Guideline of 1997).

* The design response spectrum of the seismic ground motion of level 2 stipulated in “Explanation of General (part re-posted to Guideline of 1997) was calculated based on the record of the Great Hanshin-Awaji Earthquake by statistically processing the maximum response value where one free vibration system of a structure with a damping factor of 5% is assumed (original processing of this document).

2.5 Principle of verification of seismic performance

2.5.1 General

1. In verifying seismic performance, the critical state of the respective components shall appropriately be set based on the critical state of the water supply facility vis-à-vis seismic performance.
2. Verification of seismic performance shall be conducted by verifying that the state of the respective components which shows a change due to design seismic ground motion does not exceed the critical state of the respective components which is set in accordance with condition 1.

The critical state of each seismic performance shall be as follows:

- 1) The critical state of seismic performance 1 shall appropriately be decided within a range in which the mechanical characteristics of the respective components of the water supply facility does not exceed the elastic region as a result of an earthquake.

- 2) The critical state of seismic performance 2 shall appropriately be decided within a range in which the components of the water supply system do not give a serious impact to the facility and can easily recover even though elastic deformation of the component of the water supply facility has occurred.
- 3) The critical state of seismic performance 3 shall appropriately be decided within a range in which the components of the water supply system do not give a serious impact to the facility and can recover even though elastic deformation of the component of the water supply facility has occurred.

2.5.2 Critical state of components

The critical state of seismic performances 1, 2, and 3 of the respective components of a water supply facility are set, classifying them into distribution reservoir and similar structure, ground water tanks, buried pipelines, shafts, covered conduits, utility conduits, shield tunnel, water pipe bridges, and structures related to the water supply system.

Of these components, the distribution reservoir and similar structure and buried pipeline are shown in Table 2.5.1.

Table 2.5.1 Critical state of seismic performances 1, 2, and 3 of respective components

Water supply facility	Component	Seismic performance 1	Seismic performance 2	Seismic performance 3
Distribution reservoir and similar structure	Components for main body construction (requiring watertightness)	Critical state in which mechanical characteristics do not exceed elastic region	Critical state in which some components make plastic but recovery from damage can be easily made	Critical state in which some components make plastic but recovery can be made from damage
	Components for main body construction (not requiring watertightness)	Critical state in which mechanical characteristics do not exceed elastic region	Critical state in which some components make plastic but recovery from damage can be easily made	Critical state in which whole facility does not collapse and recovery is not hindered even when some components are damaged
	Foundation work	Critical state in which mechanical characteristics do not exceed elastic region	Critical state in which excessive deformation or damage does not occur even when some components make plastic	Critical state in which substantial irregular subsidence does not occur even when part of foundation is damaged
Buried pipeline	Shell of integral structure pipeline	Critical state in which mechanical characteristics do not exceed elastic region	Critical state in which water does not leak even when some components make plastic	-
	Shell of joint structure pipeline	Critical state in which mechanical characteristics do not exceed elastic region	Critical state in which mechanical characteristics do not exceed elastic region	-
	Joint of structure pipeline	Critical state in which water does not leak from joint	Critical state in which water does not leak from joint	-

2.5.3 Method of verifying seismic performance

1. Seismic performance shall be verified by using an appropriate method in accordance with the design seismic ground motion, structure characteristics, and their critical state.
2. It may be assumed that 1 above is satisfied if seismic performance is verified in accordance with the provisions of “3.1 Design conditions of seismic calculation method”.

3 Seismic calculation method

3.1 Design conditions of seismic calculation method

3.1.1 General

1. Seismic performance shall be verified by using a seismic calculation method that appropriately takes the action of a seismic ground motion into consideration.
2. The critical value used for verification of seismic performance shall be set in accordance with the provision in “2.5.2 Critical state of components”.
- (3. to 7. Method of verifying each facility Omitted)

Seismic calculation methods include a static analysis method that have acceleration by an earthquake act with a structure as a static force of inertia to calculate a response and a dynamic analysis technique to calculate the dynamic response of a structure by directly inputting a time-history waveform.

A seismic ground motion is a dynamic phenomenon that changes with time. A response of a structure is also dynamic. Therefore, dynamic analysis can calculate a value closer to that actual than static analysis. Looking at the actual condition of seismic design of water supply systems, it cannot necessarily be said that dynamic analysis has widely spread. In light of the recent remarkable progress of numeric value analysis techniques and taking into consideration the global directivity of the future seismic technology of water supply systems, this Guideline aims at design basically using the dynamic analysis technique. Yet, it is expected that future accumulation of technologies is still necessary for seismic design of water supply systems using dynamic analysis to widely spread among designers.

Under the circumstances, static analysis shall be used for relatively simple structures. Designing using dynamic analysis shall be performed as much as possible for structures with a relatively long specific frequency or complicated shape, or structures with a high importance which require detailed study of earthquake resistance.

To rationally verify the seismic performance of a structure, it is important to appropriately understand its response in case of an earthquake and its state after the earthquake. Consequently, a response value used for verification of the seismic performance of a structure is calculated by using a seismic calculation method based on a rational dynamic model, taking into consideration the influences of earthquakes based on “2.3.5 Influences of earthquake to be considered in seismic design”. In this Guideline, an analysis model and technique that can appropriately assess the non-linear characteristics of materials to evaluate the form of damages to a structure in accordance with the seismic performance of a water supply system and to make the design rational are basically employed.

Verification of seismic performance is to verify that a response value for verification (iS_d) that takes a structure coefficient into consideration does not exceed a limit value for verification (R_d). In other words, it is to confirm that the following expression is satisfied:

$$iS_d/R_d \leq 1.0$$

where,

i: Structure coefficient

S_d : Response value for verification

R_d : Limit value for verification

Structure coefficient i is defined, taking into consideration the importance of a structure and the social impact when the critical state is reached and may generally be 1.0 to 1.2.

The limit value for verification must be appropriately calculated in accordance with the seismic

performance of a structure and based on "2.5.2 Critical state of components". However, the limit value for verification can also be calculated by experiment or other means.

A water supply facility has various types of structures and is installed on or in ground having various ground characteristics. Therefore, an appropriate seismic calculation method cannot be generally defined. Practically, however, the example of application of the calculation method shown in Table 3.1.1 can be used for reference.

Table 3.1.1 Example of application of seismic calculation method used for designing


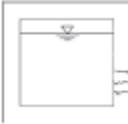

Structure			Seismic calculation method	
			Level-1 seismic ground motion	Level-2 seismic ground motion
Conveyance, transmission, distribution pipelines	Open conduit, covered conduit	Traverse direction	Dynamic analysis method or static analysis method (response displacement method, etc.)	Dynamic analysis method or static analysis method (response displacement method, etc.)
		Longitudinal direction	"	"
	Conveyance, transmission, distribution tunnels	Traverse direction	"	"
		Longitudinal direction	"	"
	Water pipe bridge Aqueduct bridge		Dynamic analysis method or static analysis method (seismic intensity method)	Dynamic analysis method or static analysis method (seismic intensity method)
	Buried pipeline	Traverse direction	-	-
		Longitudinal direction	Dynamic analysis method or static analysis method (response displacement method, etc.)	Dynamic analysis method or static analysis method (response displacement method, etc.)
Shield, shaft, etc.		"	"	
Water tanks	Distribution reservoir and similar structure		Dynamic analysis method or static analysis method (seismic intensity method or response displacement method, etc.)	Dynamic analysis method or static analysis method (seismic intensity method or response displacement method, etc.)
	Ground water tank (PC tank, steel tank, elevated tank)		Dynamic analysis method or static analysis method (seismic intensity method)	Dynamic analysis method or static analysis method (seismic intensity method)
Water purification plant main building Structures such as shed			According to Building Standard Act	According to Building Standard Act

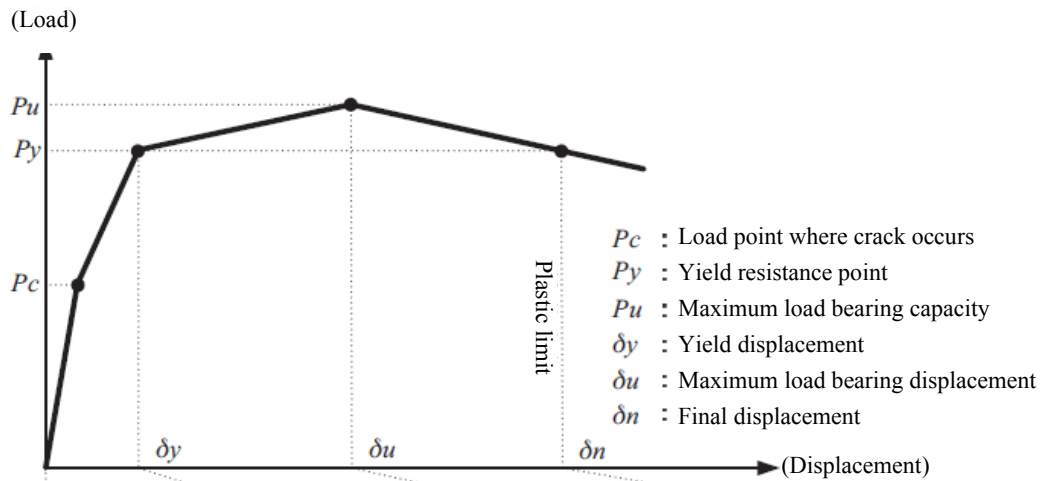
(As an example, part of verification criteria in "3.4 Seismic calculation method of distribution reservoirs and similar structures" is shown.)

3.4.3.2 Verification of seismic performance of distribution reservoir and similar structures

Table 3.4.2 shows the seismic performance and verification criteria of a distribution reservoir and similar structures that consist of reinforced-concrete components. Table 3.4.1 shows the relationship between seismic performance and critical state in accordance with load and displacement curves.

Table 3.4.2 Seismic performance and verification criteria of distribution reservoir and similar structure (RC structure)

Seismic performance	Seismic performance 1	Seismic performance 2	Seismic performance 3
Critical state*1	Critical state 1 (less than yield resistance)	Critical state 2 (less than maximum load bearing capacity)	Critical state 3 (less than final displacement and shear capacity)
Damage state	 No damage or no water leak even though a crack is generated. No need to repair	 Slight crack and water leak occur but recovery can be quickly made after earthquake.	 Crack width expands and water leaks but entire facility does not collapse. Can be repaired.
Example of verification item*2	Sectional force (bend, shear), stress intensity	Sectional force (bend, shear), plasticity rate	Displacement, bending rate, sectional force (shear)
Example of limit value for verification*3	Sectional force (bend) \leq Yield bending resistance Sectional force (shear) \leq Yield resistance Stress intensity \leq Permissible stress intensity	Sectional force (bend) \leq Max Yield bending resistance Sectional force (shear) \leq Yield resistance Plasticity rate \leq Permissible plasticity rate	Displacement \leq Final displacement Bending rate \leq Final bending rate Sectional force (shear) \leq Shear capacity
Level-1 seismic ground motion	Rank A1, rank A2	Rank B	-
Level-2 seismic ground motion	-	Rank A1	Rank A2



Seismic performance	Seismic performance 1	Seismic performance 2	Seismic performance 3
Critical state	Critical state 1 (less than yield resistance)	Critical state 2 (less than maximum load bearing capacity)	Critical state 3 (less than final displacement and shear capacity)

Figure 3.4.1 Seismic performance corresponding to load and displacement curves and critical state