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Chapter 1  General

1. 1  Introduction

This document is a reference and source of information for seismic design decisions made by staff of the Bureau of Waterworks, Tokyo Metropolitan Government (hereinafter referred to as 'the TMWB') based on the Water Supply Facilities Earthquake Resistant Construction Method Guidelines and Explanation 2009 (hereinafter referred to as 'the JWWA-Guidelines').

Moving forward, we would like to focus on high quality designs that are based on the performance designs targeted by the JWWA-Guidelines below:

(1) For design seismic ground motion, we want to extract ourselves from uniform horizontal seismic coefficient or time-history waveforms, and determine the strictest seismic ground motions for each individual structure;
(2) We want to extract ourselves from static analysis and use dynamic analysis to perform designs that reflect the actual conditions;
(3) Appropriate analysis models and analysis conditions should be determined for each structure by the responsible designers.

Seismic analysis in this document is purely a tool to assist designers make decisions during the design process. This is not to say that designers just need to follow this document and achieve the verification values enclosed, but that designers need to comprehend the limits of what can be expressed through seismic analysis, and use the seismic analysis to make a holistic judgement on the seismic capability of a facility.

The TMWB will utilize this document for the foreseeable future and build experience with dynamic analysis and other factors of seismic design.

1. 2  Range of Applications

This document is mainly applicable for distribution reservoirs and similar structures of the TMWB. This document can also, however, be used as a reference for fundamental approaches to design seismic ground motion settings, applications of dynamic analysis and details of various kinds of analysis for structures other than distribution reservoirs and similar structures, such as ground-work tanks, shafts, covered conduits. However, structures other than distribution reservoirs and similar structures will have differing natural periods, facility distributions and seismic damage characteristics to distribution reservoirs and similar structures, so these factors should also be considered with design performed with reference to the JWWA-Guidelines and other standards in addition to this document. Design seismic ground motion settings should essentially be performed with consideration of the structure's natural period, and analysis performed with reference to Seismic Impact, Seismic Calculation Method, and Verification of Seismic Performance in sections 3.3 and 3.4.4 to 3.4.6 of the JWWA-Guidelines.
Chapter 2  Fundamentals of Seismic Design

2.1 Procedure of Seismic Design

Water supply facilities are to be designed to achieve the seismic performance required dependent on the level of importance of the specific facility (seismic calculations are to verify that the respective facility achieves the required seismic performance).

Seismic design of new facilities is to essentially adhere to the procedure identified in Fig. 2.1 below.

1. Selection of construction site
   — Select site to construct facility.

2. Setting seismic performance in accordance with the importance of the water supply facility
   — Categorize water supply facilities by importance and determine the required level of seismic performance based on that importance.
   — Refer to 2.2.

3. Geotechnical investigation at construction site and soil survey of site
   — Perform as required based on the importance of the water supply facility and the soil and ground conditions of the selected site.
   — Refer to 2.3.

4. Selection of structural form and determination of facility specifications
   — Refer to the JWWA-Guidelines.

5. Setting design seismic ground motion
   — Determine Level-1 and Level-2 design seismic ground motion.
   — Refer to 2.4.

6. Seismic calculation
   — Create a model of the structure and perform analysis using the appropriate seismic calculation method.
   — Refer to 3.2 and 3.3 (distribution reservoirs and similar structures).

7. Verification of seismic performance
   — Verify that the water supply facilities achieve the seismic performance specified in (2) above.
   — Refer to 3.4 (distribution reservoirs and similar structures).

* Feedback is required for (5) to (7) based on investigation results.

Fig. 2.1: New Facility Seismic Design Flow

For seismic diagnosis and design for seismic reinforcement of existing structures, perform (1) Survey of Facility Condition instead of (1) Selection of construction site above, and follow (7) Verification of Seismic Performance with (8) Reinforcement Design, and (9) Seismic Calculation and Verification of Seismic Performance Following Reinforcement.
2. Setting Seismic Performance in Accordance with the Importance of the Water Supply Facility

The seismic performance required by facilities of different importance levels for the various levels of design seismic ground motion is shown in Table 2.4. In the level of importance at the TMWB, the distribution reservoirs and structures are classified as Rank A, and they 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.

<table>
<thead>
<tr>
<th>Design Seismic Ground Motion</th>
<th>Seismic Performance 1</th>
<th>Seismic Performance 2</th>
<th>Seismic Performance 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level-1</td>
<td>No loss of proper function due to earthquake.</td>
<td>No serious damage due to earthquake, limited repairs required following earthquake, no significant impact to function.</td>
<td>No serious damage due to earthquake. Repairs required following earthquake, but no significant impact to function.</td>
</tr>
<tr>
<td>Seismic Ground Motion</td>
<td>Distribution reservoirs and similar structures of the TMWB (Rank A)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level-2</td>
<td>Distribution reservoirs and similar structures of the TMWB (Rank A)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.3 Soil Survey

(1) Testing of Ground Dynamic Characteristics
The following dynamic material values are required for ground response analysis (dynamic analysis). The various material values can be directly derived through testing and surveys.
   i) Poisson ratio
   ii) Elastic wave velocity (longitudinal wave velocity $V_p$, transverse wave velocity $V_s$) or initial shear modulus of rigidity ($G_0$)
   iii) Shear modulus of rigidity – strain relation ($G / G_0 - \gamma$), attenuation constant – strain relation ($h - \gamma$)

(2) PS Logging (Elastic Wave Velocity Logging)
PS logging is a test procedure that enables the identification of detailed velocity distributions in the depth direction of boring locations. Deriving $V_p$ and $V_s$ from PS logging enables the indirect derivation of the ground Poisson ratio ($\nu$), Young’s modulus (E), and shear modulus of rigidity (G). Additionally, while it is preferable to measure surface ground natural period ($T_G$) and ground shear wave velocity ($V_s$) from the elastic wave velocity logging or PS logging, these can also be predicted from the N value.

(3) Determine Survey Items to Match Analysis Conditions
Select survey items and methodology for the soil survey based on the type of structure and the ground characteristics. When surveys and indoor testing are determined by Japanese Industrial Standards (JIS) and The Japanese Geotechnical Society (JGS) standards, the surveys and tests are to be performed according to those defined standards.
<table>
<thead>
<tr>
<th>No</th>
<th>Survey Item</th>
<th>Symbol</th>
<th>Unit</th>
<th>Test Method (Standard)</th>
<th>Where Used in Design</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Static</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dynamic</td>
</tr>
<tr>
<td>1</td>
<td>N Value</td>
<td>N</td>
<td>–</td>
<td>Standard Penetration Test (JIS A 1219)</td>
<td>Used for overall structure calculations</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Layer Thickness</td>
<td>–</td>
<td>m</td>
<td>PS logging</td>
<td>Ditto</td>
<td>○</td>
</tr>
<tr>
<td>3</td>
<td>Groundwater Level</td>
<td>–</td>
<td>m</td>
<td>PS logging</td>
<td>Liquefaction judgment, buoyancy</td>
<td>○</td>
</tr>
<tr>
<td>4</td>
<td>Deformation Coefficient</td>
<td>E₀</td>
<td>kn/m²</td>
<td>Hole Horizontal Load Test (LIT) (JIS 1421)</td>
<td>Ground spring constant</td>
<td>○</td>
</tr>
<tr>
<td>5</td>
<td>Shear Wave Velocity</td>
<td>Vₛ</td>
<td>m/s</td>
<td>Site permeability test</td>
<td>Ground natural period Tₛ</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vₚ</td>
<td>–</td>
<td>Microtremor measurement</td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>6</td>
<td>Surface Layer Ground Predominant Period and Amplification Ratio</td>
<td>T₀</td>
<td>sec</td>
<td>Microtremor measurement</td>
<td>Ground natural period Tₛ</td>
<td>△</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A₀</td>
<td>–</td>
<td></td>
<td></td>
<td>△</td>
</tr>
<tr>
<td>7</td>
<td>Permeability Coefficient</td>
<td>k</td>
<td>–</td>
<td>Soil Particle Density Test (JIS A 1202)</td>
<td>Soil load and bearing capability calculations</td>
<td>○</td>
</tr>
<tr>
<td>8</td>
<td>Ground Density in Direction of Depth</td>
<td>ρ</td>
<td>–</td>
<td>Density logging</td>
<td>Ground dynamic analysis</td>
<td>△</td>
</tr>
<tr>
<td>9</td>
<td>Weight per Unit Volume</td>
<td>γₛ</td>
<td>kn/m³</td>
<td>Soil Particle Density Test (JIS A 1203)</td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>10</td>
<td>Moisture Content</td>
<td>ω</td>
<td>–</td>
<td>Void ratio (ε), Degree of saturation (Sr)</td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>11</td>
<td>Wet Density</td>
<td>ρ₀</td>
<td>–</td>
<td>Bearing capability, subsidence, soil pressure, slope stability calculation</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Average particle size</td>
<td>D₁₀</td>
<td>%</td>
<td>Liquefaction judgment</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Fine Fraction Content Ratio</td>
<td>Fc</td>
<td>%</td>
<td>Fine Fraction Content Ratio Test (JIS A 1223)</td>
<td>Ditto</td>
<td>○</td>
</tr>
<tr>
<td>14</td>
<td>Cohesion (Cohesive Soils)</td>
<td>C</td>
<td>kn/m³</td>
<td>Soil Triaxial Compression Test (UJ) (JGS 0521)</td>
<td>Bearing capability, soil pressure, slope stability calculation</td>
<td>○</td>
</tr>
<tr>
<td>15</td>
<td>Angle of Internal Friction (Sandy Soils)</td>
<td>φ</td>
<td>–</td>
<td>Soil Liquid Limit and Plastic Limit Test (JIS A 1205)</td>
<td>Ditto</td>
<td>○</td>
</tr>
<tr>
<td>16</td>
<td>Plasticity Index</td>
<td>I₀</td>
<td>–</td>
<td>Liquefaction judgment, soil category</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Compression Index (Cohesive Soils)</td>
<td>Cₐ</td>
<td>–</td>
<td>Soil Consolidation Test (JIS A 1217)</td>
<td>Consolidation settlement (e-log graph)</td>
<td>△*</td>
</tr>
<tr>
<td>18</td>
<td>Volume Compressive Coefficient</td>
<td>mₐ</td>
<td>–</td>
<td></td>
<td>Ditto</td>
<td>△*</td>
</tr>
<tr>
<td>19</td>
<td>Shear Modulus Of Rigidity/Initial Shear Modulus Of Rigidity</td>
<td>G/G₀</td>
<td>–</td>
<td>Repeated Load Triaxial Test (JGS A 0542)</td>
<td>Dynamic deformation characteristics, seismic response analysis</td>
<td>△*</td>
</tr>
<tr>
<td>20</td>
<td>Attenuation Constant</td>
<td>h</td>
<td>–</td>
<td>Repeated Load Hollow Cylinder Torsion Test (JGS 0543)</td>
<td>Ditto</td>
<td>△*</td>
</tr>
<tr>
<td>21</td>
<td>Liquefaction Strength Ratio</td>
<td>R</td>
<td>–</td>
<td>Repeated Load Undrained Triaxial Test (JGS 0541)</td>
<td>Liquefaction judgment, liquefaction strength characteristics evaluation, effective stress judgment</td>
<td>△</td>
</tr>
</tbody>
</table>

Legend:  ○: Often used; △: Sometime used. *: Nos. 17 - 20 used for 1-dimensional ground response analysis.
(4) Determining the Engineering Bedrock

The engineering bedrock is the bedrock used for seismic design when creating a model of the ground, and is a critical part of seismic design. The engineering bedrock spreads uniformly across the applicable site, and is assumed to be the upper surface of a ground layer with a much higher constant (remains linear) shear wave velocity than the upper ground layers. The engineering bedrock must be determined from a wider overall perspective, with ground information from surrounding sites utilized in addition to data for the applicable site. The engineering bedrock is the upper surface of a contiguous layer with an N value of 50 or above, and generally with a shear wave velocity of \( V_s \geq 300 \text{ m/s} \) or higher. However, the engineering bedrock can be appropriately determined when there are detailed ground survey results available, and consideration must be given to individual site ground characteristics in the judgment. The engineering bedrock for seismic damage estimation in the Tokyo Regional Disaster Prevention Plan is set at \( V_s \geq 500 \text{ m/s} \) or above, so when using Method 2 for Level-2 seismic ground motion (refer to 2.4), there may be the need to make assumptions concerning ground structure from ground survey depth to the engineering bedrock. This is because confirming the bearing layer (ground layer with targeted N value of 50 or higher, and where \( V_s \) is around 300 m/s or higher) is the main purpose of standard ground surveys as part of the design process, and ground surveys down to where \( V_s \geq 500 \text{ m/s} \) are rarely performed.

![Suiteki-kun One Point Lesson](image)

(5) Calculating Ground Natural Period

There are two types of ground natural period; the natural period \( T_G \) during normal periods (minimal strain), and the natural period \( T'_G \) during earthquakes (large strain). The former can be actually measured through PS logging and microtremor measurement. The latter can either be calculated using the convergent rigidity from the 1-dimensional ground response analysis results (refer to 2.4.4 (6)), or derived from earthquake observation records. When these are not possible, the ground natural period during normal times \( T_G \) can be calculated from the N value, with shear wave velocity \( V_s \) derived from Table 2.11. The ground natural period during an earthquake \( (T'_G) \) is most important, however, to evaluate the ground’s behavior during an earthquake, so the fundamental approach is to calculate the ground natural period during an earthquake \( (T'_G) \) when dynamic analysis is performed.
2. 4 Design Seismic Ground Motion

(1) Method of Determining Level-1 Seismic Ground Motion
There are two methods of determining level-1 seismic ground motion in the JWWA-Guidelines; the conventional method of determining level-1 seismic ground motion (the method in the 1997 JWWA-Guidelines), and the economy verification is also examined. The fundamental stance of the TMWB is to utilize the conventional method for determining level-1 seismic ground motion for the seismic design of the TMWB’s water supply facilities.

(2) Flowchart for Determining Level-1 Seismic Ground Motion
The flowchart for determining level-1 seismic ground motion (static analysis) is shown in Fig. 2.21 below.

Fig. 2.21: Flowchart for Determining Level-1 Seismic Ground Motion (Static Analysis)
(3) Deriving Seismic Coefficient for Distribution Reservoirs and Similar Structures
(Common for Level-1 and Level-2 Seismic Ground Motion)

i Omission of Distribution Reservoirs and Similar Structure Natural Period Calculation
Distribution reservoirs and similar structures, in general, have high horizontal shear rigidity, and a relatively small natural period. Additionally, they are positioned close to the ground surface and so the ground surface acceleration is used as the design seismic coefficient (note from p.125 of the JWWA-Guidelines/Overall).

ii Categorization of Aboveground Structure and Underground Structure
When the majority of the structure is underground (when around 2/3s of the structure is underground), use the design seismic coefficient at the center of gravity of the structure derived by linear interpolation of the seismic coefficient between the ground surface and the engineering bedrock (note from p.125 of the JWWA-Guidelines/Overall).

iii Structures Located Below the Engineering Bedrock
When the center of gravity of the structure is located below the engineering bedrock, use the standard horizontal seismic coefficient at the engineering bedrock for the design horizontal seismic coefficient.

iv Categorization of When to Use Seismic Coefficient Method or Seismic Deformation Method
The JWWA-Guidelines do not clarify when to apply the differing analytical methods in static analysis (p.59 of the JWWA-Guidelines/Overall).
The analytical method should be selected with consideration for the ground conditions and structural characteristics of the relevant structure. The seismic coefficient method should be used when the inertial force will be the dominant factor, and the seismic deformation method should be used when the impact of ground deformation during an earthquake will be the dominant factor. When the relative impacts of the differing methods are not clear, use the seismic deformation method for structures that are more than around 10 m deep. Refer to 3.2.3 (1) for details of the categorization of the different analytical methods.
This does not mean that the seismic deformation method is used for all underground structures, but that for those structures that are determined to be underground structures, the seismic deformation method should be used when it is determined that the impact of ground deformation during an earthquake will be the dominant factor.

(4) Method of Determining Level-2 Seismic Ground Motion

There are four methods in Table 2.9 for determining level-2 seismic ground motion in the JWWA-Guidelines. The TMWB determines level-2 seismic ground motion as shown below, categorized by dynamic analysis and static analysis.

i Dynamic Analysis: Use Both Method 2 and Method 3, and Utilize a Minimum of Three Waveforms

ii Static Analysis: Use the Greater Design Seismic Coefficient of Methods 2 and 4

Table 2.9: Method of Determining Level-2 Seismic Ground Motion (JWWA-Guidelines’ Stipulation)

<table>
<thead>
<tr>
<th>Determination Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method 1: Evaluate seismic ground motion with an assumed hypocenter fault, and use the seismic ground motion at the respective location.</td>
</tr>
<tr>
<td>Method 2: Use the seismic ground motion from the relevant Regional Disaster Prevention Plan, etc.</td>
</tr>
<tr>
<td>Method 3: Use records of strong earthquakes with seismic coefficients of 6-upper to 7 for sites that have similar ground conditions (ground type).</td>
</tr>
<tr>
<td>Method 4: Design seismic coefficients and design response spectrum based on observations from the Southern Hyogo Prefecture Earthquake.</td>
</tr>
</tbody>
</table>

(5) Flowchart for Determining Level-2 Seismic Ground Motion (Static Analysis)
Fig. 2.25: Flowchart for Determining Level-2 Seismic Ground Motion (Static Analysis)

1. Soil and ground conditions (ground Type, etc.)
2. Engineering bedrock time history acceleration waveform for method 2
   i. Northern Tokyo Bay earthquake
   ii. Tama Region Epicentral Earthquake
   iii. Tachikawa Fault Earthquake
3. 1-dimension ground response analysis
4. Ground surface standard horizontal seismic coefficient for method 2
   \[ K_{h02} = \frac{\alpha_{max}}{980} \]
   (\( \alpha_{max} \): Max. surface acceleration)
5. Ground surface standard horizontal seismic coefficient for method 4
   \[ K_{h02} \] for Type I ground: 0.70
   \[ K_{h02} \] for Type II ground: 0.80
   \[ K_{h02} \] for Type III ground: 0.60
6. Use the greater of the max. value from method 2 and the design horizontal seismic coefficient from method 4.
7. Underground structures
   Use seismic ground motion determined at ⑤.
8. Method 2
   Determine from the max. acceleration \( \alpha'_{max} \) at the bedrock of the applied wave.
   \[ K'_{h02} = \frac{\alpha'_{max}}{980} \]
9. Method 4
   \[ K'_{h02} = 0.50 \]
10. Structure characteristic coefficient \( C_s \)
11. Modification factor for zone \( C_z \)
12. Structure design horizontal seismic coefficient \( K_{h2} \)
   \[ K_{h2} = C_s \cdot K_{h02} \]
13. Structure characteristic coefficient \( C_s \)
14. Depth of structure center of gravity \( Z \)
15. Surface layer ground thickness \( H \)
16. Structure design horizontal seismic coefficient \( K_{h2} \)
   \[ K_{h2} = C_s \left( \frac{K_{h02} - Z}{K_{h02} - K'_{h02}} \right) \]

* Use only for areas where an earthquake intensity of 6-upper or greater is predicted for the Tachikawa Fault Earthquake.
  (Refer to (2) for details.)
(6) Flowchart for Determining Level-2 Seismic Ground Motion (Dynamic Analysis)

Follow the flowchart in Fig. 2.28 for dynamic analysis of level-2 seismic ground motion. Select a minimum of three waveforms to use as input seismic ground motion for the dynamic analysis.

![Flowchart](image)

Fig. 2.28: Flowchart for Determining Level-2 Seismic Ground Motion (Dynamic Analysis)
(7) Level-2 Seismic Ground Motion – Method 2 (Regional Disaster Prevention Plan)

For level-2 seismic ground motion, select multiple seismic ground motion waveforms from Table 2.14 which show the seismic damage estimation, perform a 1-dimensional ground response analysis on those waveforms and select the one that has the greatest impact. Waveforms can be used directly for dynamic analysis. For static analysis, derive the ground surface standard horizontal seismic coefficient from the largest maximum surface acceleration value. For 1-dimensional ground response analysis, the basic approach is to use FDEL, DYNEQ or other analysis codes that can appropriately evaluate acceleration levels when shear strain is high.

Table 2.14: Input Seismic Ground Motion Waveforms (Select More than 1) for Method 2 1-Dimensional Ground Response Analysis

<table>
<thead>
<tr>
<th>Earthquake Assumption</th>
<th>Engineering Bedrock Surface Maximum Acceleration</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Tokyo Bay Earthquake</td>
<td>697 gal</td>
<td>Tokyo ward area (exclude Toshima ward, Kita ward, Itabashi ward and Nerima ward.)</td>
</tr>
<tr>
<td>Tama Region Epicentral Earthquake</td>
<td>739 gal</td>
<td>Toshima ward, Kita ward, Itabashi ward, Nerima ward and Tama area.</td>
</tr>
<tr>
<td>Tachikawa Fault Earthquake</td>
<td>—</td>
<td>Use for areas with 6-upper earthquake.</td>
</tr>
</tbody>
</table>

(*) Waveform with the maximum acceleration from all meshes (wave from with time history acceleration of $V_s \geq 500$ m/s at engineering bedrock surface.)

Fig. 2.29: Seismic Coefficient Distributions for Assumed Earthquakes

The hypocenters have not been determined for the Northern Tokyo Bay Earthquake, or the Tama Region Epicentral Earthquake, so similar earthquakes may have a hypocenter directly under any area of the metropolitan region. As a result of this, we must consider the worst case scenario for water supply facilities when using these as the design seismic ground motion, and use the waveform for the mesh directly above the hypocenter (consider that the hypocenter may be epicentral to water supply facilities).

The locations of the hypocenters have been determined for the Tachikawa Fault earthquake and the Genroku Kanto earthquake, with those locations having specific characteristics. For this reason, use the waveform in the mesh at the location of the water supply facilities when using these earthquakes for design seismic ground motion (do not move the hypocenter, consider the damping of the seismic wave over distance from the hypocenter).

Fig. 2.16: Overview of Definitions when Using Predicted Earthquakes for Design Seismic Ground Motion
Waveforms to Use for Method 3 (Epicentral)

For method 3 (epicentral) earthquakes, use the measured waveform data from the Hyogo Prefecture Nanbu Earthquake, Niigata Prefecture Chuetsu Earthquake or the Niigata Prefecture Chuetsu Offshore Earthquake shown in Table 2.18 and perform 1-dimensional ground response analysis. Select the following waveform based on those results.

i. Method 3-1: Short period predominant → Choose 0 or 1 waveform.
   Waveform where ground surface response velocity spectrum is predominantly 0.1 - 0.3 sec.
ii. Method 3-2: Long period predominant → Choose 0 or 1 waveform.
   Waveform where ground surface response velocity spectrum is predominantly 0.8 - 2 sec.
iii. Method 3-3: Ground natural period predominant → Choose 0 or 1 waveform.
   Waveform where ground surface response velocity spectrum is predominantly around $T_g$: the ground natural period during an earthquake.

There is no need to select the waveform in method 3 with the applicable period characteristics when the waveform from method 2 (predicted earthquakes in Regional Disaster Prevention Plan) is of a size that encompasses any of the waveforms from i. to iii. above. For this reason, there will be two to three waveforms selected in method 3 (epicentral earthquake).

Table 2.18: Input Seismic Ground Motion Waveforms for Method 3 (Epicentral Earthquake)

<table>
<thead>
<tr>
<th>Earthquake Name</th>
<th>Waveform Name</th>
<th>Seismic Ground Motion Characteristics</th>
<th>Max. Accel.</th>
<th>Seismic Intensity</th>
<th>Measurement Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-① 1995 Southern Hyogo Prefecture Earthquake</td>
<td>Kobe Marine Observatory Bridge NS</td>
<td>Strong earthquake observation on solid ground</td>
<td>818 gal</td>
<td>6-Upper</td>
<td>Ground surface</td>
</tr>
<tr>
<td>B-② 2004 Mid Niigata Prefecture Chuetsu Earthquake</td>
<td>JR Takatori Station NS</td>
<td>Strong earthquake observation near seismic intensity 7 area.</td>
<td>604 gal</td>
<td>6-Upper</td>
<td>Ground surface</td>
</tr>
<tr>
<td>B-③ 2007 Niigata-ken Chuetsu-oki Earthquake</td>
<td>K-NET Tokamachi NS</td>
<td>Epicentral observation of predominantly short-period epicentral strong earthquake</td>
<td>1,716 gal</td>
<td>6-Upper</td>
<td>Ground surface</td>
</tr>
<tr>
<td>B-④ Kariwa Village NS (Japan Meteorological Agency)</td>
<td>K-NET Tokamachi NS</td>
<td>Epicentral observation of predominantly long-period strong earthquake</td>
<td>465 gal</td>
<td>6-Upper</td>
<td>Ground surface</td>
</tr>
</tbody>
</table>

Waveforms to Use for Method 3 (Subduction-Zone Type)

Select a method 3 (subduction-zone type) waveform when any of the below are applicable:

i. Construction site has high risk of liquefaction, or on soft ground;
ii. Structure will be influenced by sloshing (PC tank);
iii. Facility is predicted to experience 6-Upper seismic intensity from Genroku Kanto Earthquake (refer to Fig. 2.29).

There is no need to select a subduction-zone type waveform when none of the above are applicable.

For method 3 (subduction-zone type), perform 1-dimensional ground response analysis on the observed waveforms for either of the earthquakes shown in Table 2.19; the 2003 Tokachi-Oki Earthquake and the 2011 Tohoku Region Pacific Coast Earthquake; and select the waveforms (1 or more) that have the same predominant period band response velocity as the object being evaluated (ground predominant period, storage water predominant period, structure predominant period, etc.).

Table 2.19: Input Seismic Ground Motion Waveforms for Method 3 (Subduction-Zone Type)

<table>
<thead>
<tr>
<th>Earthquake Name</th>
<th>Waveform Name</th>
<th>Seismic Ground Motion Characteristics</th>
<th>Max. Acceleration</th>
<th>Seismic Intensity</th>
<th>Measurement Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-① 2003 Tokachi-Oki Earthquake</td>
<td>K-NET Chokubetsu EW</td>
<td>Records of strong subduction-zone earthquake where long-periods were predominant.</td>
<td>785 gal</td>
<td>6-Upper</td>
<td>Ground surface</td>
</tr>
<tr>
<td>C-② 2011 Tohoku Region Pacific Coast Earthquake</td>
<td>K-NET Hitachi NS</td>
<td>Records of strong subduction-zone earthquake where short-periods were predominant.</td>
<td>1,598 gal</td>
<td>6-Upper</td>
<td>Ground surface</td>
</tr>
</tbody>
</table>
Table 2.33: Examples of Input Seismic ground motion Waveforms for Method 3 (Epicentral)

i  Short period predominant

ii  Long period predominant

iii  Near ground natural period most predominant

Waveforms to Use for Input Seismic Ground Motion

i. Short period: K-NET Tokamachi NS

ii. Long period: JR Takatori Station NS

iii. Near ground natural period: Port Island NS
3. General

(1) Selecting Seismic Calculation Method

As shown in Table 3.1, static analysis, of which the TMWB has many design examples, is fundamentally used for seismic calculation methods for distribution reservoirs and similar structures. But for specific facilities, dynamic analysis can be used concomitantly. For new designs or reinforcement design (large scale facilities), cross-section design is performed using static analysis, and the cross-section is verified using dynamic analysis. Modify design cross-sections and repeat design calculations when the required seismic performance is not achieved in the dynamic analysis. However, static analysis is used in the seismic diagnosis to determine if seismic reinforcement design is required.

Table 3.1: Seismic Calculation Method of Distribution Reservoirs and Similar Structures

<table>
<thead>
<tr>
<th>Design Seismic Ground Motion (Target Seismic Performance)</th>
<th>New Structure</th>
<th>Existing Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seismic Diagnosis</td>
<td>Seismic Reinforcement Design</td>
</tr>
<tr>
<td>Level-1 Seismic Ground Motion (Seismic Performance 1)</td>
<td>Static analysis (linear)</td>
<td>Static analysis (linear)</td>
</tr>
<tr>
<td>Level-2 Seismic Ground Motion (Seismic Performance 2)</td>
<td>Static analysis (linear) Dynamic analysis (non-linear)</td>
<td>Static analysis (linear)</td>
</tr>
</tbody>
</table>

* Large scale facilities: Applicable to purification plants (capacity greater than 100,000 m³ per day) and water stations (effective capacity greater than 5,000 m³ per day). In addition to the structures above, verify distribution reservoirs and similar structures that have a capacity of 5,000 m³ or above using dynamic analysis.

(2) Seismic Design Flowchart for Distribution Reservoirs and Similar Structures of the TMWB

The seismic design flowchart for the distribution reservoirs and similar structures of the TMWB is shown in Fig. 3.1. At the TMWB, dynamic analysis is performed for seismic ground motion of new designs or large-scale reinforcement design, and then the seismic ground motion that is the most severe for the applicable structure is used by looking at the ground response analysis of the various design seismic ground motions.

The basic process is for the design cross section to be determined by static analysis, and for that to be verified via dynamic analysis. If the design cross section achieves unsatisfactory dynamic analysis results, the design cross section is redefined through static analysis. The dynamic analysis model is modified based on the new design cross section and the dynamic analysis verification repeated. This is to confirm that the new design cross section is satisfactory.

The TMWB essentially uses 2D FEM for the dynamic analysis, and the FEM model must be modified if the design cross section is changed. There is a lot of time and effort involved in these cases, so care is taken to ensure that the design cross section will not need to be changed in dynamic analysis.

One example of this is the use of nonlinear static analysis (pushover analysis). Pushover analysis is still a form of static analysis, but it directly verifies the nonlinear properties of the structure, in many cases achieving responses similar to dynamic analysis. In this way, re-verification through pushover analysis of the design cross section determined through linear static analysis can minimize modifications of the cross section at the dynamic analysis stage.
Fig. 3.1: Seismic Design Flow

1. **Start**
   - Collect documentation, survey site, soil survey, etc.

2. **Setting design seismic ground motion**
   - Level 1: Conventional method
   - Level 2: Dynamic analysis: methods 2 & 3
   - Static analysis: methods 2 & 4

3. **Perform ground response analysis**
   - Input waveform (methods 2 & 3)

4. **Seismic design from static analysis (L1)**
   - All cross sections
   - For above ground distribution reservoirs and similar structures:
     - Ground surface acceleration \( \div 980 \)
     - Std. horizontal seismic coefficient

5. **Seismic design from static analysis (L2)**
   - All cross sections
   - Use greater value from method 2 and 4 for L2 horizontal seismic coefficient
   - For above ground distribution reservoirs and similar structures:
     - Ground surface acceleration \( \div 980 \)
     - Std. horizontal seismic coefficient

6. **Dynamic analysis verification (L2)**
   - Analyze design cross section determined through static analysis
   - Min. 3 waveforms from method 2 and method 3 for input seismic ground motion.
   - 2-3 representative cross sections are used.

7. **Verify**
   - OK

8. **Determine design cross section**

9. **Existing/Setting design seismic ground motion**
   - Level 1: Conventional method
   - Level 2: Static analysis: methods 2 & 4

10. **Perform ground response analysis**
    - Input waveform (methods 2 & 3)

11. **Seismic diagnosis from static analysis**
    - Seismic ground motion levels 1 & 2

12. **Reinforcement design from static analysis**
    - Seismic ground motion levels 1 & 2

13. **Dynamic analysis verification (L2)**
    - Analyze design cross section determined through static analysis
    - Min. 3 waveforms from method 2 and method 3 for input seismic ground motion.

14. **Verify**
    - OK

15. **Determine reinforcement cross section**

---

*: As per p. 125 of Overall section of the JWWA-Guidelines, no requirement to natural period of distribution reservoirs and similar structures.

---

Fig. 3.1: Seismic Design Flow
3. Static Analysis

(1) Static Analysis Procedures

<table>
<thead>
<tr>
<th>Determining water supply facility importance</th>
<th>Determining target seismic performance</th>
<th>Calculating ground natural period</th>
<th>Judging ground type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selecting structure type</td>
<td>Selecting foundation type</td>
<td>Determining facility specifications</td>
<td></td>
</tr>
</tbody>
</table>

START

Laying depth
- Generally down to less than 10 m.

Select analysis method

Seismic coefficient method

Setting design seismic coefficient

- Calculating structure natural period
  - L1: Conventional method
  - L2: Greater of method 2 or 4
  - Method 2: Acceleration response spectrum defined in Regional Disaster Prevention Plan
  - Method 4: Acceleration response spectrum from JWWA-Guidelines

Seismic deformation method

Setting design seismic coefficient

- Determining design displacement amplitude
  - L1: Uh method
  - L2: Greater of method 2 or 4
  - Method 2: Ground response analysis
  - Method 4: JWWA-Guidelines: Uh method
  - Surface layer ground natural period used for the Uh method is to be determined using calculation method from 3.2.4 (vii) Ground Displacement Amplitude.

Constructing Analysis Model

- Seismic Coefficient Method
  - Normal loading:
    - Fixed load, full load, earth pressure, water pressure, buoyancy
  - Load during earthquake:
    - Inertia force, hydrodynamic pressure, earth pressure

- Seismic Deformation Method
  - Normal loading:
    - Fixed load, full load, earth pressure, water pressure, buoyancy
  - Load during earthquake:
    - Inertia force, hydrodynamic pressure, ground displacement, peripheral shear force

Structure calculations (structure, foundation piles)

- (Normal, Level-1 seismic ground motion)
  - Verify sectional force (Normal, Level-1 seismic ground motion)
    - Calculate initiation stress (bending, shear, axial)

Verify sectional force (Normal, Level-1 seismic ground motion)

- (Normal, Level-1 seismic ground motion)
  - Calculating structure natural period

Yes

- Setting design seismic coefficient
  - Calculating structure natural period

Laying depth
- Generally down to depth greater than 10 m.

END

Fig. 3.7: Design Flow for Static Analysis

*1: Calculation of natural period not required for distribution reservoirs and similar structures.
(2) Acquiring Load During Earthquake (Example)

Earth Pressure: Use of modified Mononobe-Okabe formula
Hydrodynamic Pressure: Use of Westergaard’s formula
Soil Spring / Pile Spring: Use of formula from section IV on substructure work in Specifications for Highway Bridges (Japan Road Association, March 2012)
Buoyancy: Calculate buoyancy during earthquake categorizing non-liquefied and liquefied layers (Sewage Facility Seismic Design Examples of Calculations for Processing Plants and Pump Plants (Ver. 2); Japan Sewage Works Association, 2002)

Fig. 3.22: Examples of Obtaining Earthquake Loading (Seismic Coefficient Method)
3. 3 Dynamic Analysis

(1) Dynamic Analysis Procedures

Fig. 3.1: Design Flow for Dynamic Analysis

(2) Selection of Differing Analysis Model System

As part of the dynamic analysis of distribution reservoirs and similar structures, it is important to appropriately evaluate the effects of the dynamic interaction between the structures and the ground during an earthquake, as there is significant contact between the structures and the ground over a wide area.

Table 3.1 shows the methods to express the dynamic interaction in the ground and structure analysis models system, and the standards used for the dynamic analysis of the TMWB's distribution reservoirs and similar structures. The model system essentially consists of the independent structure model expressed using a spring model of the boundary of the structure and the ground, and the combined ground-structure model expressed through an FEM model of the earthquake behavior of the entire surface ground layer (shallower than the engineering bedrock).
Table 3.11: Types of Models for Distribution Reservoirs and Similar Structures and the TMWB Standards

<table>
<thead>
<tr>
<th>Analysis Models</th>
<th>TMWB Standards</th>
<th>Structure Models</th>
<th>Ground Models</th>
<th>Nonlinear Ground Properties</th>
<th>General Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined Ground-Structure Model</td>
<td>Facilities Where Liquefaction is Not a Concern</td>
<td>Use total stress model</td>
<td>Beam model or FEM model</td>
<td>Use effective stress model</td>
<td>Total Stress Model</td>
</tr>
<tr>
<td>Independent Structure Model</td>
<td>Facility in Solid Ground</td>
<td>Use total stress model</td>
<td>Spring model</td>
<td>Use total stress model</td>
<td>Engineering bedrock</td>
</tr>
</tbody>
</table>

The fundamental approach of the TMWB is to use the combined ground-structure model. For distribution reservoirs and similar structures that will not be impacted by the surface layer ground, for example, those structures that are on engineering bedrock-like solid ground, an independent structure model is used as there will be limited influence from dynamic interaction between the ground and the structure, and displacement of the structure will essentially not be an issue.

(3) Selection of Calculation Methods

The methods available to calculate dynamic response values (dynamic analysis methods) are the time history response analysis method and the spectrum method. For time history response analysis, there is direct integration, response analysis in frequency domain, and mode analysis. Direct integration is the main type of time history response analysis used for dynamic analysis of the TMWB’s distribution reservoirs and similar structures, as nonlinear response needs to be derived to verify seismic performance 2 for level-2 seismic ground motion, and because the aim is to evaluate accumulated time-history displacement.

(4) Constructing Analysis Model

An outline for constructing an example of a combined ground-structure model for dynamic analysis of the TMWB’s distribution reservoirs and similar structures is shown in Fig. 3.35. For dynamic analysis of distribution reservoirs and similar structures, the behavioral characteristics of the structure and the ground during an earthquake need to be fully comprehended and the following items verified. It is important to construct a suitable model for each facility to be verified. Refer to the main document for the details of each item.

Main Items for Constructing Analysis Models

- Determining input seismic ground motion
- Creating structure model
- Creating model of water in the structure
- Determining damping conditions
- Modelling of other details
- Modelling of the ground
- Modelling of ground-structure interface
- Determining boundary conditions
- Determining drainage conditions
For Combined Ground-Structure Model

Fig. 3.35: Samples for Constructing Analysis Model (Combined Ground-Structure Model)

**Ground Models**
- Non-liquefaction: Total stress model
- Liquefied layer: Effective stress model
- Nonlinear model (Total stress model)
- Base viscous boundary

**Modelling of Ground-Structure Interface**
- Use joint elements to express detachment or sliding, etc., in the ground-structure contact surface.

**Structure, Foundation Pile Models**
- Beam elements: Appropriate nonlinear evaluation
- Nonlinear model
  - Skeleton curve: Tri-linear model (Appropriately evaluate splits and cracks, yield, and proof stress)
  - Hysteretic curve: Modified Takeda model, tri-linear model (Masing rule)

**Input Seismic Ground Motion**
- Time history acceleration waveform
- Apply 2D wave to engineering bedrock

**Boundary Conditions (Lateral)**
- Horizontal roller boundary, viscous boundary, similar free boundaries, etc.
- Ensure sufficient lateral area (for example, five times the vertical distance)

**Boundary Conditions (Base)**
- Viscous boundary

**Damping**
- Hydrostatic damping of total system: automatically considered due to non-linear hysteretic characteristics
- Total system viscous damping: considered in viscous boundary
- Subterranean radiation damping: considered in viscous boundary

**Modelling of EXP**
- Nonlinear springs
- Transmission of compressive force only
(5) Determining Input Seismic Ground Motion

i  Types of Seismic Ground Motion
Define design seismic ground motion and input seismic ground motion to be used for dynamic analysis of distribution reservoirs and similar structures as shown in i. and ii. below.
A design seismic ground motion will be determined from advance investigation, and from this, an input seismic ground motion that can be directly input to the analysis model needs to be determined to perform dynamic analysis of the distribution reservoirs and similar structures.
A time history acceleration waveform is to be used for the input seismic ground motion.

(i) Design Seismic Ground Motion
This is determined in section 2.4 of these guidelines. This is the seismic ground motion that is determined prior to constructing the analysis models used for seismic calculations of the distribution reservoirs and similar structures. This is the seismic ground motion waveform that has not been aligned with the analysis models and code that will be used for distribution reservoirs and similar structure seismic calculations.

(ii) Input Seismic Ground Motion
This has been aligned with the analysis models and code for the distribution reservoirs and similar structures, and is a seismic ground motion that can be directly input into the models (time history acceleration waveform). This may be a conversion of a design seismic ground motion as required. For example, in cases where the design seismic ground motion is the E + F waveform at the engineering bedrock, the input seismic ground motion can be determined by converting this into a 2E wave, for example, that does not accept impact of surface layer ground (does not include reflective wave), for the analysis model.

ii  Methods to Input Seismic Ground Motion
As shown in Fig. 3.37, dynamic analysis of distribution reservoirs and similar structures is done upwards of the engineering bedrock, with the input seismic ground motion applied to the engineering bedrock, in the 1-dimension ground FEM model and the 2-dimension combined ground-structure model.
When analysis is performed on the independent structure model, the time history acceleration waveform at the ground surface is applied to the various elements and nodes of the structure.

Fig. 3.37: Methods to Input Seismic Ground Motion

Incident wave (E) and Reflective wave (F)
The seismic wave is the sum of the incident wave (E) from the hypocenter, and the reflective wave (F) from the surface layer ground.
The reflective wave from the surface layer ground is not present at the ground outcrop, so the reflective wave and the incident wave are the same, resulting in a seismic wave of 2E.

Fig. 3.38: Incident Wave (E) and Reflective Wave (F)
Source: Page 35, Introduction to Civil Structure Seismic Design (Japan Society of Civil Engineers, 2002)
3.4 Verification of Seismic Performance

(1) General
The seismic performance of the TMWB's facilities is determined by the design seismic ground motion and the importance categorization of the facility (refer to 2.2). The critical state for various seismic performances are outlined below.

i  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 do not exceed the elastic region as a result of an earthquake.

ii 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 plastic deformation of the component of the water supply facility has occurred.

iii 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 plastic deformation of the component of the water supply facility has occurred.

Verification of seismic performance shall be conducted by verifying that the state of the respective components which show a change due to design seismic ground motion does not exceed the determined critical state of the respective components. The relationship between seismic performance and critical state, damage state and limit value for verification are shown in Table 3.14 and Fig. 3.53. The limit value for verification shall be determined corresponding to the determined seismic performance and the relevant seismic ground motion.

Table 3.14: Seismic Performance and Critical State, Damage State and Limit Value for Verification

<table>
<thead>
<tr>
<th>Seismic Performance</th>
<th>Seismic Performance 1</th>
<th>Seismic Performance 2</th>
<th>Seismic Performance 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical State *1</td>
<td>Critical State 1</td>
<td>Critical State 2</td>
<td>Critical State 3</td>
</tr>
<tr>
<td></td>
<td>(less than yield resistance)</td>
<td>(less than maximum load bearing capacity)</td>
<td>(less than final displacement and shear capacity)</td>
</tr>
<tr>
<td>Damage State</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>No damage or no water leak even though a crack is generated. No need to repair.</td>
<td>Slight crack and water leak occur but recovery can be quickly made after earthquake.</td>
<td>Crack width expands and water leaks but entire facility does not collapse. Can be repaired.</td>
<td></td>
</tr>
<tr>
<td>Level-1 Seismic Ground Motion</td>
<td>Rank A</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Level-2 Seismic Ground Motion</td>
<td>–</td>
<td>Rank A</td>
<td>–</td>
</tr>
<tr>
<td>Limit Value for Verification*2</td>
<td>Static Analysis Stress ≤ Allowable stress</td>
<td>Sectional force (bending) Max yield bending resistance Sectional force (shear) ≤ Shear capacity</td>
<td>Curvature ≤ Curvature at maximum load bearing capacity Sectional force (shear) ≤ Shear capacity</td>
</tr>
<tr>
<td>Dynamic Analysis</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

*1: Critical State

*2: Limit Value for Verification

---

Critical state is evaluated by verifying that the state of damage of each of the materials of the structure is within the critical state for each material.

In addition to the limit values shown in the table, allowable crack width and allowable water leak volume, amongst others, can be used to directly verify watertightness. Additionally, level of deformation to assure water stopping performance of waterstops and other similar structures are options for expansion joint verification. Limit values for verification for each material do not need to be consistent across the entire structure, with different limit values identified for each material to correspond to the seismic performance of the structure as a whole.
(2) Judging Failure Mode

Material failure modes are essentially bending failure or shear failure. It is important that shear failure mode is avoided, even when there is damage as a result of an earthquake, to prevent brittle failures and also to endure the proper toughness of the materials.

The JWWA-Guidelines do not specify about failure mode judgment, but the TMWB judges failure mode as per Table 3.16 for new designs, seismic diagnosis, and for reinforcement design.

<table>
<thead>
<tr>
<th>Category</th>
<th>Judgment Location</th>
<th>Judging Failure Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Design</td>
<td>Linear</td>
<td>End of member</td>
</tr>
<tr>
<td></td>
<td>Nonlinear</td>
<td>Location where plastic hinge occurs</td>
</tr>
<tr>
<td>Existing Seismic Diagnosis</td>
<td>Linear</td>
<td>End of member</td>
</tr>
<tr>
<td>Seismic Reinforcement Design</td>
<td>Linear</td>
<td>End of member</td>
</tr>
<tr>
<td></td>
<td>Nonlinear</td>
<td>Location where plastic hinge occurs</td>
</tr>
</tbody>
</table>