Damage by the 2011 Great East Japan Earthquake

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CONTENTS
- Outline of the earthquake and damage
- Damage to water supply facilities
- Unusual phenomena: an abrupt increase in flow rate and a decrease in water pressure of water distribution system in spite of no damage to pipelines
- Conclusions

Epicenter and JMA SI

Aftershocks

Peak Ground Acc. and Vel. (1)

Peak Ground Acc. and Vel.

Large PGA observed sites

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Site Code</th>
<th>PGA (cm/s²)</th>
<th>PGV (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 K-NET Tagokura</td>
<td>MYG004</td>
<td>2.933</td>
<td>108</td>
</tr>
<tr>
<td>2 K-NET Sogama</td>
<td>MYG012</td>
<td>2.019</td>
<td>64</td>
</tr>
<tr>
<td>3 K-NET Hokoda</td>
<td>IBR035</td>
<td>1.644</td>
<td>74</td>
</tr>
<tr>
<td>4 K-NET Sendai</td>
<td>MYG013</td>
<td>1.808</td>
<td>83</td>
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<tr>
<td>5 K-NET Hokoda</td>
<td>IBR015</td>
<td>1.752</td>
<td>71</td>
</tr>
<tr>
<td>6 K-NET Iwaki</td>
<td>TO009</td>
<td>1.444</td>
<td>48</td>
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<td>7 K-NET Shinakawa</td>
<td>PK016</td>
<td>1.425</td>
<td>63</td>
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<tr>
<td>8 K-NET Nishigaya</td>
<td>PK010</td>
<td>1.335</td>
<td>41</td>
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<tr>
<td>9 K-NET Omiya</td>
<td>IBR024</td>
<td>1.312</td>
<td>47</td>
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<tr>
<td>10 K-NET Haga</td>
<td>TG018</td>
<td>1.305</td>
<td>52</td>
</tr>
</tbody>
</table>

PGA and PGV: Vectorial Summation of 3 Components
Bandpass filter to calculate velocity waveform: 0.3-15Hz
Damaged area by tsunami

Great tsunami hit residential area.

Damage to houses

Overturn of building

Wash away and overturn of building

Most of RC buildings were not damaged severely even in coast area.
Characteristics of damage

- Earthquake: Ground shaking
  - Ground failure (Liquefaction, Slope failure, etc.)
- Tsunami: Inundation
  - Washing away
  - Scouring

Damage by ground shaking and liquefaction

Tsunami (Washing away)

Tsunami (Inundation)

Damage by tsunami (Scouring and washing away)

No damage to earthquake-proofing pipe

High density of calcium chloride in water
No damage to earthquake-proofing pipe

Comparison of damage rate

Earthquake proofing rate and damage rate

Characteristics of damage to water supply facilities
- Damage to aged pipelines with small diameter
- Damage to air valves
- No damage to earthquake-proofing pipeline
- Malfunction of purification plants in flooded area

Flow rate and water pressure at a water distribution plant of Tokyo

Occurrence of the unusual phenomena of water distribution system

<table>
<thead>
<tr>
<th>Name</th>
<th>Seismic Intensity</th>
<th>Observation</th>
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<tbody>
<tr>
<td>Suppore City</td>
<td>3</td>
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<tr>
<td>Adachi City</td>
<td>4</td>
<td>N/A</td>
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<tr>
<td>Minato City</td>
<td>5+</td>
<td>N/A</td>
</tr>
<tr>
<td>Shinkansen City</td>
<td>6+</td>
<td>Yes</td>
</tr>
<tr>
<td>Tokyo Metropolitan</td>
<td>9+</td>
<td>Yes</td>
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<tr>
<td>Fukuoka City</td>
<td>8+</td>
<td>N/A</td>
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<tr>
<td>Tottori City</td>
<td>9+</td>
<td>Yes</td>
</tr>
<tr>
<td>Chubu City</td>
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</tr>
<tr>
<td>Tokyo Metropolitan</td>
<td>9+</td>
<td>Yes</td>
</tr>
<tr>
<td>Fukuoka City</td>
<td>8+</td>
<td>N/A</td>
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<tr>
<td>Shinkansen City</td>
<td>6+</td>
<td>Yes</td>
</tr>
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<td>Osaka City</td>
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<td>Hyogo Prefecture</td>
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</tr>
</tbody>
</table>
Flow rate and water pressure at a water distribution plant of Osaka

Response velocity spectra at Nagoya and Osaka

Mechanism of draw of water

Predominant period of water in receiving water tank

\[ T_s = \frac{2\pi}{1.58 \frac{g}{l} \tanh \left( 1.58 \frac{h}{l} \right)} \]

where,
- \( T_s \): Predominant period of sloshing (s)
- \( g \): Acceleration of gravity (m/s²)
- \( h \): Depth of water (m)
- \( l \): \( \frac{1}{2} \) of length of basement (m)

Maximum displacement of water caused by sloshing

\[ d = \frac{0.527 \cos \left( 1.58 \frac{h}{l} \right)}{g \omega_l^2} \quad \theta_s = 1.58 \frac{g}{l} \tanh \left( 1.58 \frac{h}{l} \right) \]

where,
- \( g \): Acceleration of gravity (m/s²)
- \( h \): Depth of water (m)
- \( l \): \( \frac{1}{2} \) of length of basement (m)
- \( \omega_l \): Resonance velocity spectrum of predominant period of sloshing (m/s)
- \( \theta_s \): Predominant circular frequency

Predominant period of water in receiving water tank
Concluding remarks (1)

- The entire damage to water supply pipelines is not revealed in flooded areas by tsunami. We must collect all damage data and analyze it to learn the lessons from this disaster.

- Effect of earthquake-proofing for pipeline was verified. We must accelerate the earthquake proofing, especially for aged facilities.

- Force of tsunami acted on a buried pipe is not clear. The effect of tsunami must be studied soon.

Concluding remarks (2)

- If sloshing of water in receiving water tank is occurred by an earthquake, draw of water to receiving water tank from pipeline starts by error of sensor of water level in the receiving water tank. Sloshing of water in receiving water tank, therefore, seems to be one of the causes of unusual phenomena.

Thank You for Your Kind Attention