Study report of priority evaluation of earthquake resistance on water supply facilities focused on the restoration process of water supply

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1. INTRODUCTION

The priority evaluation of earthquake resistance is determined by the earthquake performance, the role as water supply base of an emergency, the presence of water supply to hospitals and shelters, and a degree of difficulty of recovering.

On the other hand, it is common to be shown the effect of earthquake resistance as using the indices of an earthquake resistance rate of water distribution stations, water purification plants and water pipes. These indices are effective to manage the progress of earthquake resistance on water facilities for water supply utilities, but it is difficult to understand the effect of earthquake resistance for water users. It is important for water users to know when we can be supplied water and water facilities get recovered, so it is considered that it would be more understandable for water users to put “the number of recovering days” and “suppliable water amount” into the indices of an effect earthquake resistance.

Therefore, we carried out a priority evaluation as indices of an effect of earthquake resistance focused on the restoration process of water supply with the aim of clarifying the effect of earthquake resistance from water user’s point of view.

2. STUDY CONDITIONS

Evaluation Method

The estimation method is shown in Figure 1.

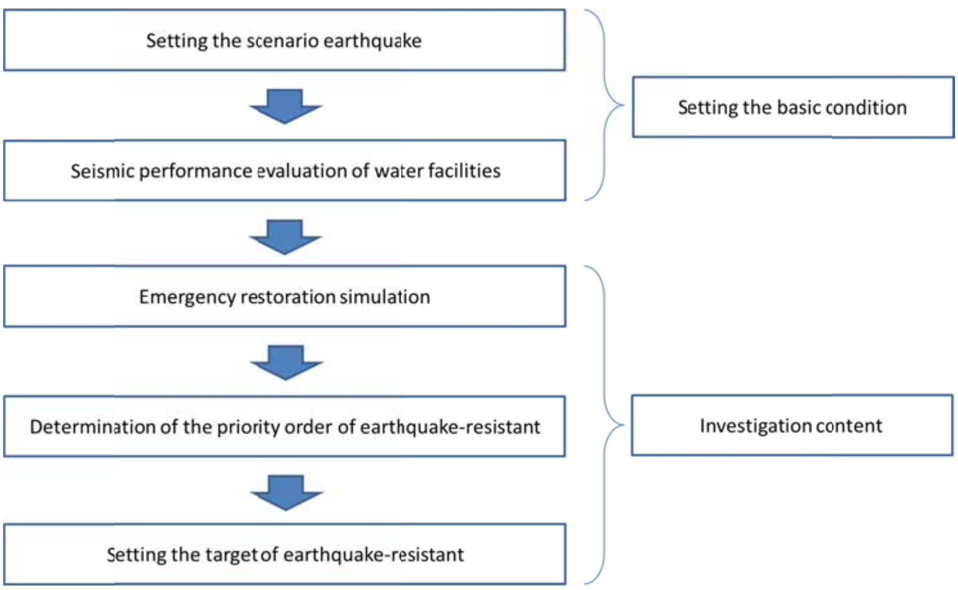

Figure 1 Evaluation method of the investigation

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Target Area

The target area on this report is located in Tokai area and has 700,000 people designated. It is located nearby the coast Pacific Ocean and it is consisted of a plain mainly for residents and northern mountainous areas.

Severe Earthquake Fault Model and Hypocentral Distribution

We selected Nankai Trough Earthquake as a scenario earthquake which is used in earthquake-resistant plan. Nankai Trough is about 4000m deep trench which is located in south of coast of Shikoku and regarded as large-scale earthquake occurrence area. The focal area of a scenario earthquake is between Suruga Bay in east part and Palau Oceanic Ridges in south west part. In deep direction, the range is regarded as about 40km which is from the trough axis to low frequency earthquake occurrence area which is a little bit deeper from the border of the plate.

The distribution of seismic intensity of Nankai Trough Earthquake is shown in Figure 2[1). It is assumed that strong quakes would be taken place in wide area of southern part of Japan.

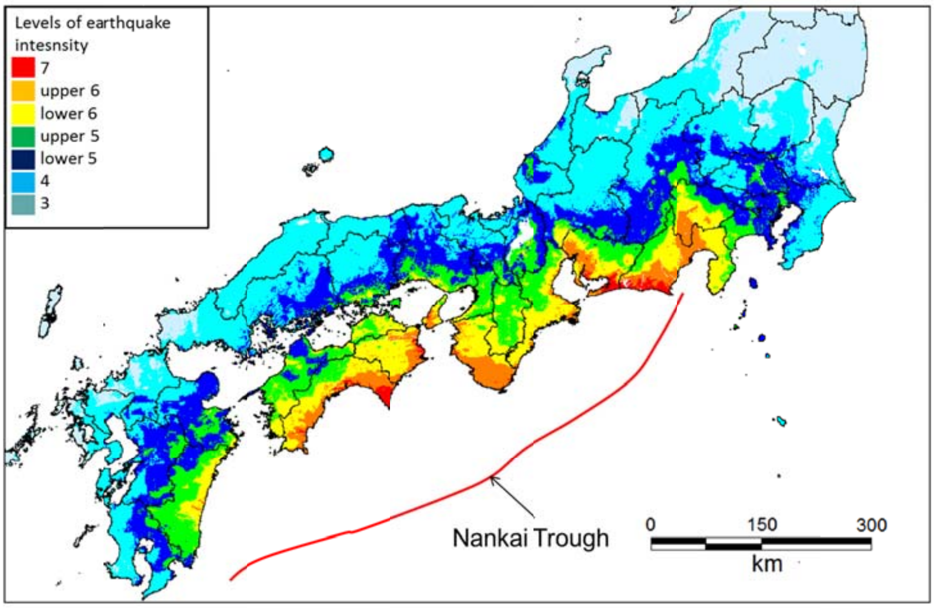

Figure 2 The maximum seismic intensity distribution[1)

We determine 4 areas where the strong earthquake would occur by strong wave calculation based on the characteristics of Pacific Coast of Tohoku Earthquake and magnetic earthquakes occurred in the world, and predict the degree of seismic intensity in each area.

There are 4 cases of seismic distribution data and we determined the case that would get damaged at the most. Figure 3 shows the distribution of seismic intensity of the subject area.

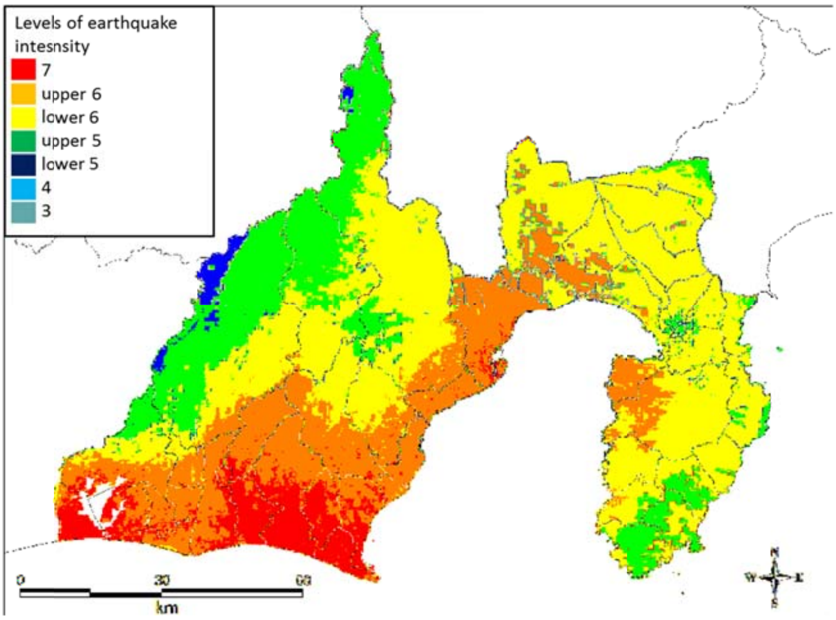

Figure 3　Seismic intensity distribution of the subject area

3. SEISMIC PERFORMANCE EVALUATION OF WATER FACILITIES

Civil Structures

Seismic performance evaluation of civil structures is that we reflect seismic detailed diagnosis that is conducted between 2013 and 2015, and we evaluate civil structures based on the established year and ground conditions. Then, we determine seismic properties in each level of earthquake. Figure 4 shows the flow chart of the evaluation for civil structures.

According to the diagnostics result, if the structures are diagnosed with not securing seismic performance of level 2, we evaluate them again based on the seismic intensity distribution of Nankai Trough earthquake. If the structures haven't diagnosed yet, we reflect the information of the scenario earthquake in each region and evaluate whether the structures get damaged or not based on the established year, construction method, ground conditions and base method.

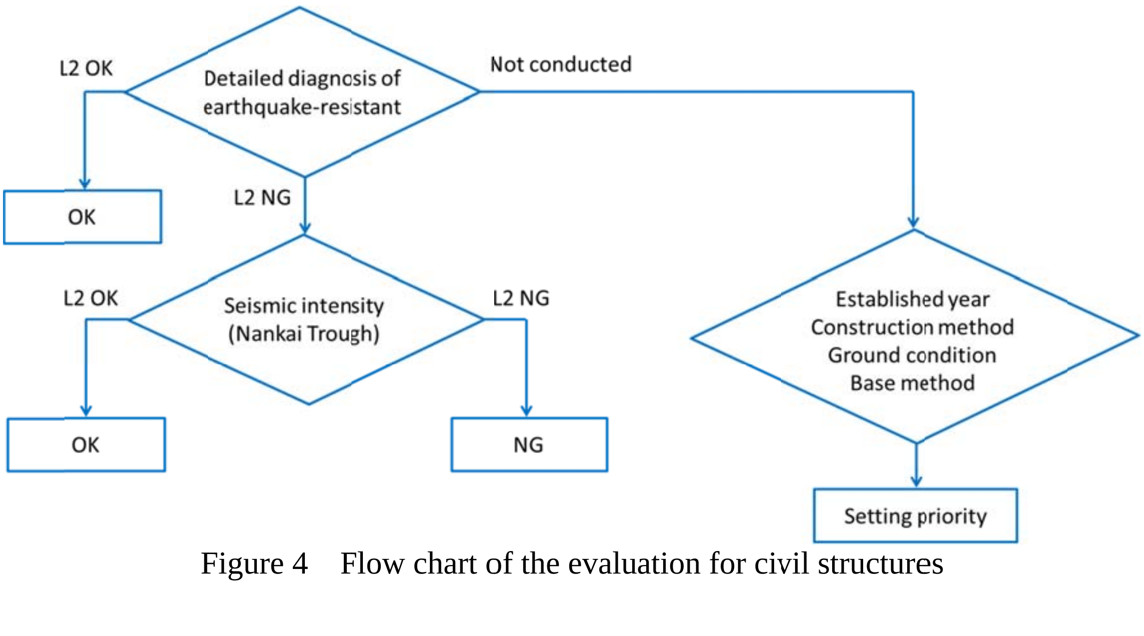

Figure 4　Flow chart of the evaluation for civil structures

Table 1　Estimation of earthquake-resistant

Category	Seismic Performance	Content	Estimation Standard
1	OK	Securing seismic performance of level 2	・OK by seismic detailed diagnosis ・"Ⅰ"structures or "Ⅲ"structures with great ground condition
2	Not necessary	Securing seismic performance of level 1	・"Ⅱ" and Rank B structures
3	Not good	Securing seismic performance of level 1	・"Ⅱ" structures with great ground condition ・"Ⅲ"structures without great ground condition
4	Bad	There is a possibility getting damaged	・NG by seismic detailed diagnosis ・"Ⅱ" structures without great ground condition ・Neither "Ⅰ""Ⅱ" "Ⅲ"

Ⅰ：Structures built after 1997（made of RC,PC or Steel）
Ⅱ：Structures built after 1979（made of RC）or built after 1985（made of Steel）
Ⅲ：Structures with spread foundation built after 1980（made of PC and its capacity is less than 10,000 ㎥）
Current seismic standard : seismic performance in "The ordinance of technical standards on water facilities"[2)]

According to the result of the seismic performance evaluation, 80% of the water intake stations could not secure the seismic performance and 40% of purification stations could not secure the seismic performance, either. 50 % or more of the water supply facilities are not securing seismic performance due to the established year, and it may severely damage a lot of water facilities.

Water Pipes

Seismic performance evaluation of water pipes is that we predict the damage by earthquakes using pipeline damage prediction equation[3)].

$$R_m(v)\ (\text{spot/km}) = C_p \times C_d \times C_g \times C_l \times R(v) \qquad \text{(Eq.1)}$$

$$R_m\ (\text{spot}) = R_m(v) \times L \qquad \text{(Eq.2)}$$

（※（Japan Water Works Association)）

・Breakage rate : $R_m(v)$
・correction factor for type of pipe : C_p
・correction factor for pipe diameter : C_d
・Correction factor for terrain and soil : C_g
・Correction factor for liquefaction : C_l
・Maximum acceleration of seismic motion : v
・Breakage ratio（spot/km） : R（v）
・The number of breakage in mesh : R_m
・Length of pipes in mesh（km） : L

As a result of the seismic damage prediction, we get damaged on water pipes in 1566 places and the breakage ratio is 0585 spot/km. This breakage ratio is between Kobe and Nishinomiya when Hyougoken-Nambu Earthquake occurred and it would take a lot of time to restore.

We calculate the supply interruption rate from the breakage ratio in each region. The supply interruption rate is calculated by the relation between available water supply ratio and breakage ratio[3]. As a result, the total the supply interruption rate is 71.2% and it resulted that it influences water supply in wide range area.

Table 2 Breakage ratio in each region

Region	Ratio of water outage (%)	Length (km)	Number of the breakage	Breakage ratio (spot /km)	Restoration term (day / squad)
A	45.24%	1192	597	0.318	1543
B	64.15%	338	172	0.488	362
C	55.03%	808	683	0.455	1315
D	25.20%	206	63	0.174	207
E	44.00%	77	23	0.294	49
F	66.80%	56	29	0.507	56
Total	73.50%	2677	1566	0.585	3532

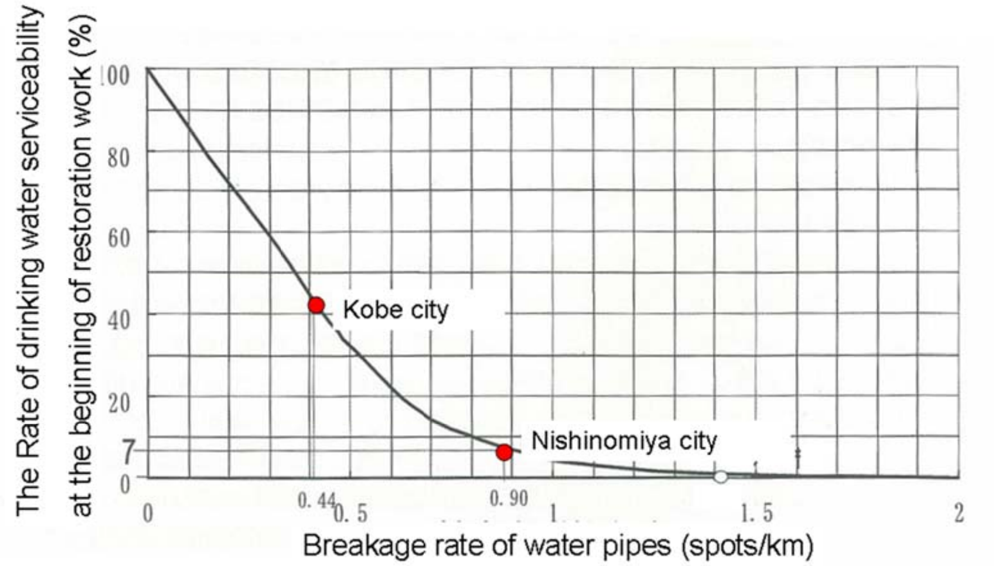

Figure 5 Rate of drinking-water serviceability at the beginning of restoration work[4]

4. EMERGENCY RESTORATION SIMULATION

Basic Policy

We predict emergency restoration term based on the result of estimating disaster on water facilities. The supply interruption term tends to be subject to the emergency restoration of water pipes so it is assumed that the restoration term should be calculated by the damage of water pipes[4], but we obtained the result that main facilities could get a lot of damages due to the damage prediction of civil and architect structures, too. Therefore, it would be adequate to consider the emergency restoration of water facilities in purification stations as well.

Restoration Speed of the Structures

We determine the emergency restoration term of each water facilities from the past big earthquake disasters. Table 3 shows the emergency restoration term of water facilities. These values show emergency restoration and we don't estimate the repairing and reinforcement.

Table 3 Emergency restoration term of water facilities

Name of water failities		Restoration term (day)
Purification stations	Rapid filtration (not securing sesmic performance)	30
	Slow filtration (not securing sesmic performance)	30
	Rapid filtration (securing sesmic performance)	15
	Slow filtration (securing sesmic performance)	15
	Membrane filtration	3
Water sources		3
Distribution stations		3
Pumping stations		3

Restoration Speed of the Water Pipes

Table 4 shows the restoration speed of water pipes of each diameter. We calculate the emergency restoration term of water pipes based on the restoration speed[4)] and the restoration speed of its diameter of 700mm or more is calculated by "Earthquakes Countermeasure Manual Guidance"[3)]

Table 4 Restoration speed of water pipes[4)5)]

Diameter(mm)	Restoration speed (spot/squad・day)
ϕ700～	0.20
ϕ500～600	0.25
ϕ300～450	0.50
ϕ200～250	1.00
ϕ150	1.00
ϕ100	2.00
～ϕ75	2.00

Setting the Restoration Process

On this investigation, we set that 70 emergency restoration squads would be sent to the damaged portions in the subject area for one day, and they are supposed to restore water facilities stepwise. The number of squads is calculated by population served and the scale of the earthquake[6)]. The number of restoration squads in each area is determined by the ratio of the restoration term in each area to the total of restoration term. We multiple this ratio by 70 squad/day and set the number of restoration squads in each area. In terms of the restoration, we can't send water to the residents when purification stations got damaged even if feeder pipes are restored perfectly. Therefore, we restore water facilities from water intake stations in order. Figure 6 shows the restoration step of water facilities.

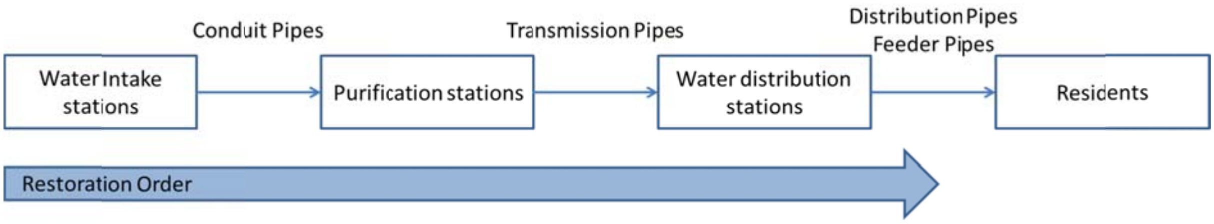

Figure 6 Restoration step on water facilities

Result

We found out the available water supply and target water supply from the restoration speed and restoration process, and available water supply is calculated from the restoration status of distribution pipes and feeder pipes when it is restored by the method. Target water supply is determined by the earthquake countermeasures of waterworks of the subject area. Then, we calculate the deficient term of emergency water supply in each area and we assume that water facilities started to be restored from the area that has longer deficient term. Further, we defined that the deficient term of emergency water supply is between the occurrence of the earthquake and the time that available water supply exceeds target water supply. Figure 7 shows deficient term of emergency water supply and restoration process. According to the figure, the water facilities are restoring in the order of water intake stations, conduit pipes, purification stations, and water supply starts increasing when feeder pipes are restored. Then, available water supply starts increasing at the same time that water distribution stations and distribute pipes are restored, and water supply would be stable when the end of the feeder pipes are restored.

On the investigation, we state the calculation method of a priority order using 4 areas of the deficient term. Figure 8 shows the transition of target water supply and available water supply in each area, and Table 5 shows the restoration term and priority order in each area.

As you can see the Table 5, area “d” has the longest term of the restoration of feeder pipes and distribution pipes, and it would get damaged at the most. In area “c”, it takes a lot of time to recover conduit pipes and transmission pipes, but distribution pipes and feeder pipes are restored in 2 weeks and necessary water supply are secured and the deficient term is shortest.

In this way, we focus on the deficient term of emergency water supply and promote the earthquake resistance countermeasure from the longest deficient term.

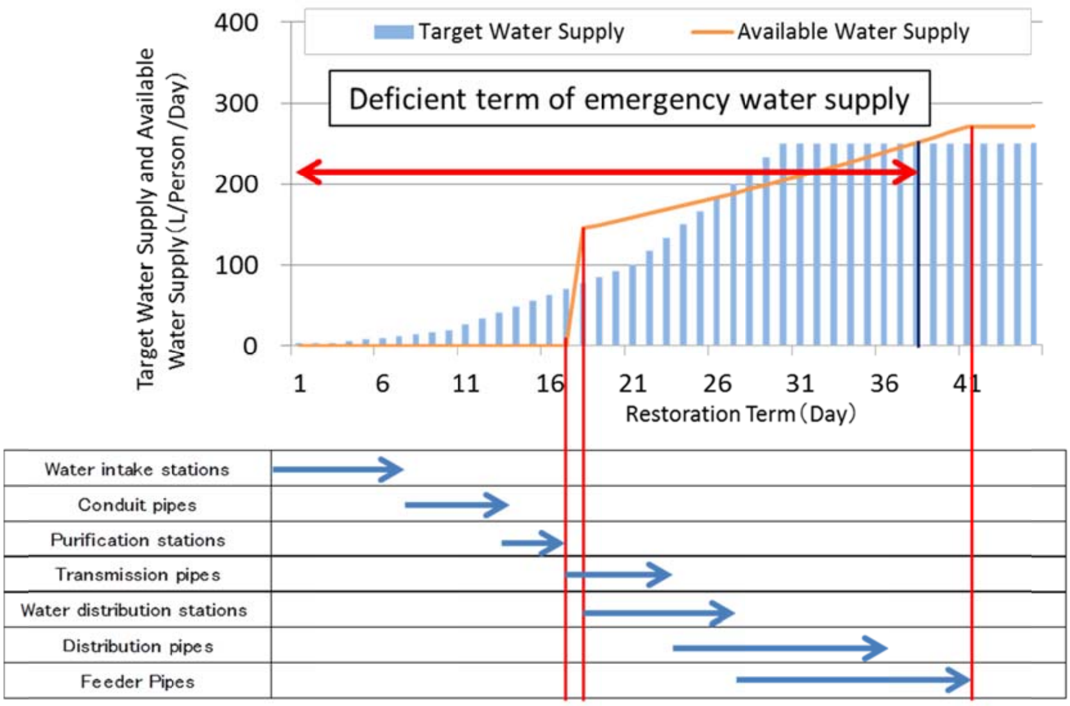

Figure 7　Deficient term of emergency water supply and restoration process

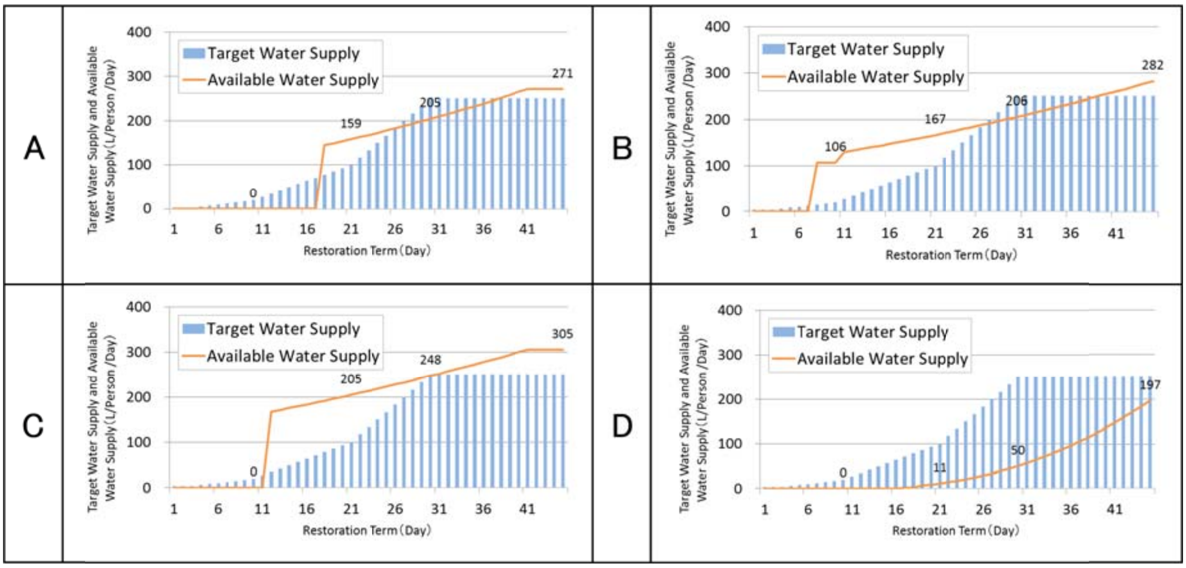

Figure 8　The transition of target water supply and available water supply in each area

Table 5　Setting priority order in each area

Area	Restoration term (day)			Restoration group (squad/day)	Priority order
	Conduit pipes and transmission pipes	Purification station	Distribution pipes and feeder pipes		
A	17	19	38	3	2
B	8	–	37	8	3
C	12	–	12	7	4
D	14	33※	45以上	28	1

※ It is restoring in stages.

5. SETTING THE TARGET OF EARTHQUAKE-RESISTANT

We mentioned how we set the order in each area in preceding paragraph, but the deficit of water flow would be different depending on the order of restoring water facilities.

Figure 9 shows restoration simulation before earthquake resistance in area “A”. As you can see the figure, from the occurrence of the earthquake to the 16th day, it would hardly supply water when conduit and transmission pipes are damaged even if feeder pipes are restored completely, so we need to restore conduit and transmission pipes to secure water supply. Therefore, it is considered that we reduce the damage of conduit and transmission pipes and we secure the available water supply right after the earthquake occurred.

The amount of available water supply started to be restored when conduit and transmission pipes recovered, but emergency water supply get to be deficient between 28th day and 33rd day. During this time, it is considered distribution and feeder pipes are not restored completely and they can’t afford enough water supply. Therefore, we need to take countermeasures of distribution and feeder pipes to afford enough water supplies during this period.

Figure 10 shows restoration simulation after earthquake resistance in area “A”. We assume that we reinforce 15% of conduit and transmission pipes and 10% of distribution and feeder pipes, and the reinforced pipes are not supposed to get damaged when the earthquake occurred. As you can see the graph, the available water supply exceeds the target water supply and it is considered that water supply is secured in this area even if Nankai Trough Earthquake occurred.

Thus, we set the target of earthquake resistance to secure necessary amount of water and make the effect of earthquake resistance visible. It is considered that we can show the earthquake resistance plan which is understandable for water users.

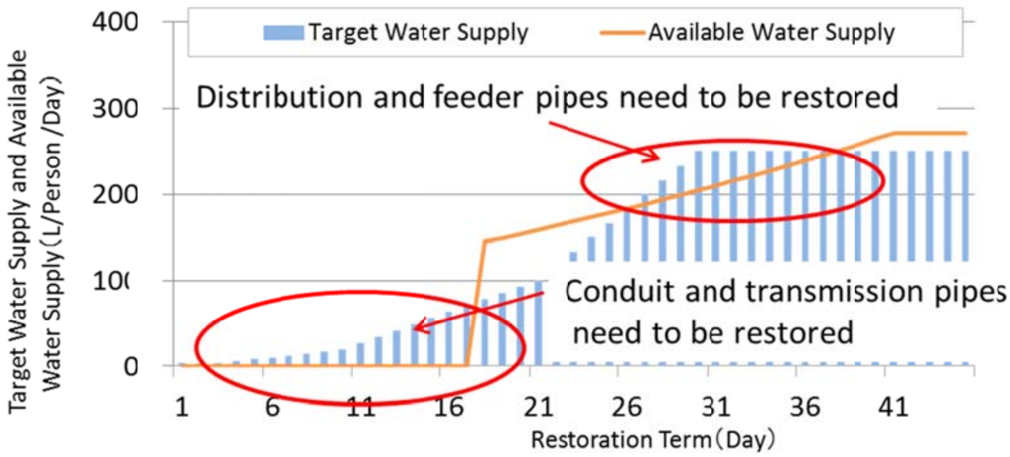

Figure 9 Restoration simulation before earthquake resistance in area “A”

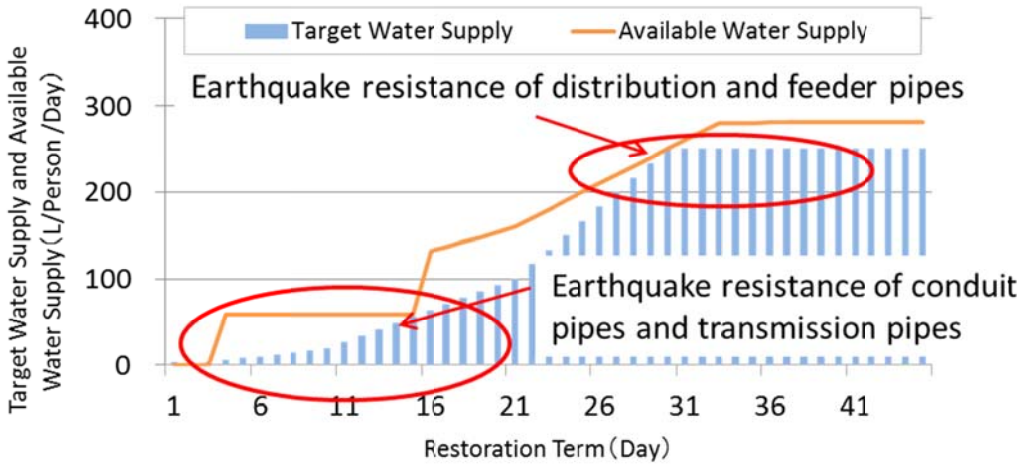

Figure 10 Restoration simulation after earthquake resistance in area "A"

6. CONCLUSION

On this investigation, we focused on the restoration process of water flow and carried out the priority evaluation of earthquake-resistance. We could show the understandable effect of earthquake-resistance for water users. We chose an examination target as a main city on this report, but if it is a small city, the number of restoration groups would be restricted and it is expected that there will be many water facilities that are not securing seismic performance. Therefore, we intend to carry out the restoration simulation on small cities and we will investigate the difference of restoration process between big cities and small cities.

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