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Cover page

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

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ABSTRACT

The priority evaluation of earthquake resistance is determined by the earthquake damage, the role as emergency water supply points, the necessity of water supply to hospitals and shelters, and the degree of recovery difficulty.

A general method to show the effect of earthquake resistance is by using the earthquake resistance rate indices of water distribution stations, purification plants and pipes. Said indices are effective for earthquake resistance management of water supply facilities, but it is difficult to comprehend the effect of earthquake resistance for the water users. It is important for the water users to know when water supply is expected to restart, so it is considered to be more convenient for the water users to mention the “required days for recovery” and “suppliable water amount” in the indices.

Therefore, a priority evaluation of earthquake effect indices focused on the restoration process of water supply was carried out to clarify the effect of earthquake resistance from the water user’s point of view.

The target is the water supply system of major cities, from the water intake to distribution, and the evaluated contents are listed below.

①The earthquake damage is evaluated in terms of the existing facilities against the earthquake scenario.

②The initial water amount and the required days for recovery are calculated by the estimation of earthquake damage.

③The recovering speed and process are determined by personnel and backup of the organization.

④The emergency water supply target is divided into stages by the number of days following the earthquake, by day 1-10, 11-21 and 22-30.

⑤The deficient period and amount of emergency water supply are calculated by comparing ③ and ④.

The effective priority evaluation of earthquake resistance was established by the above study. Furthermore, it shall provide as an advantage for establishing an intermediate target for a long-term project.

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1. INTRODUCTION

The priority evaluation of earthquake resistance is determined by the earthquake performance, the role as water supply points 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, however, it is difficult to understand the effect of earthquake resistance for the water users. It is important for the water users to know when water supply is expected to restart. Therefore it is considered that it is more understandable for water users to put “the number of recovering days” and “suppliable water amount” into the indices of an effect earthquake resistance.

Thus, a priority evaluation was carried out 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.

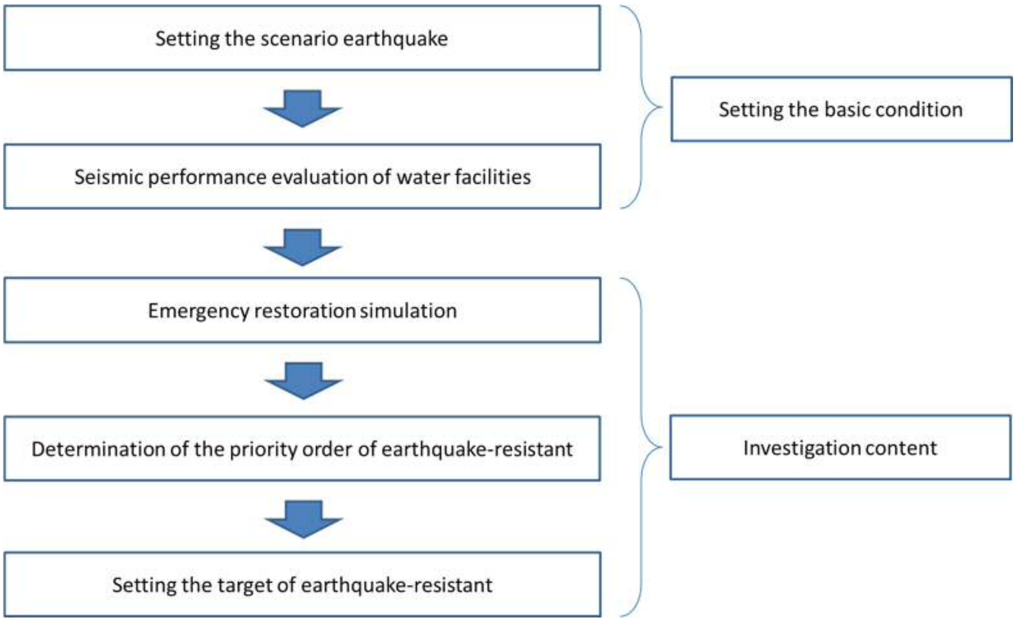

Figure 1 Evaluation method of the investigation

Target Area

The target area is a major city in the Tokai area and with a population of 700,000. It is located along the Pacific Ocean and is consisted of a plain mainly for residential areas and northern mountainous areas.

Severe Earthquake Fault Model and Hypocentral Distribution

Nankai megathrust earthquake was selected as the scenario earthquake to form the earthquake-resistant plan. The Nankai Trough is a 4000 m scale ocean trench located south of Shikoku, and regarded as a large-scale earthquake occurrence area. The fault of the earthquake model lies from the eastern part of Suruga Bay to the south-western part of the Palau Oceanic Ridges. The depth is 30-4- km, from the trough axis to the plate border and the deeper areas where the low frequencies cause earthquakes.

The distribution of seismic intensity of Nankai megathrust earthquake estimated by the Japanese Cabinet Office is shown in Figure 2[1)]. Strong quakes are assumed to occur in wide areas of southern Japan.

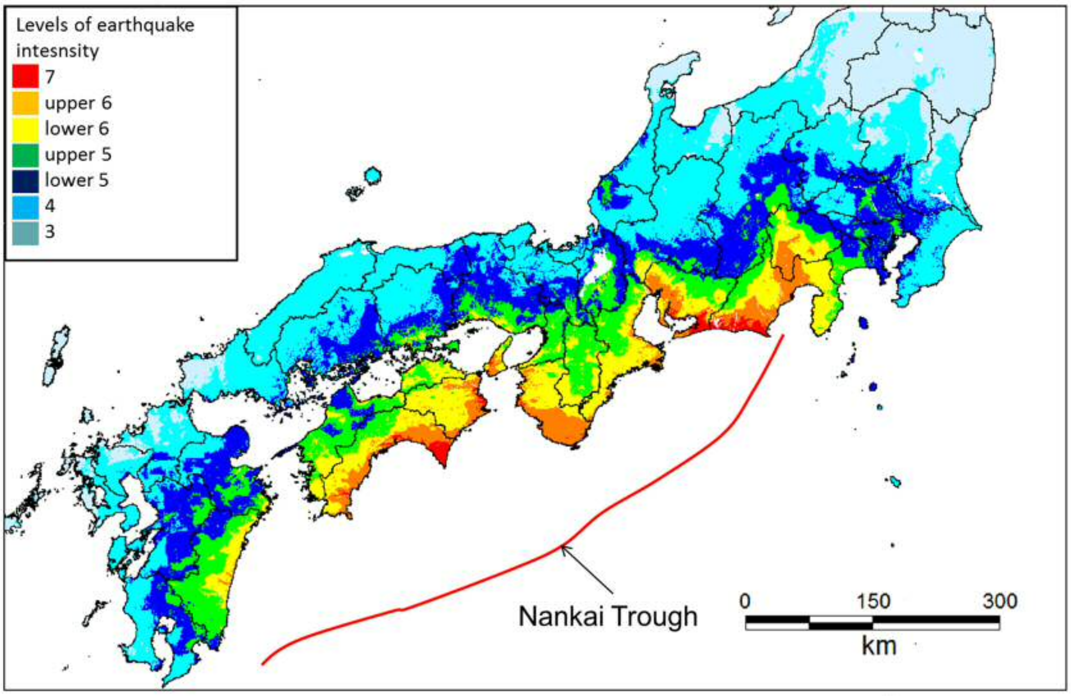

Figure 2 The maximum seismic intensity distribution[1)]

The data to predict the degree of seismic intensity was determined by setting 4 strong-earthquake areas, based on the characteristics of the Great East Japan Earthquake and other magnetic earthquakes around the world, and strong wave calculation.

The case which estimated the most critical damage was adopted for this study. Figure 3 shows the distribution of seismic intensity of the subjected area.

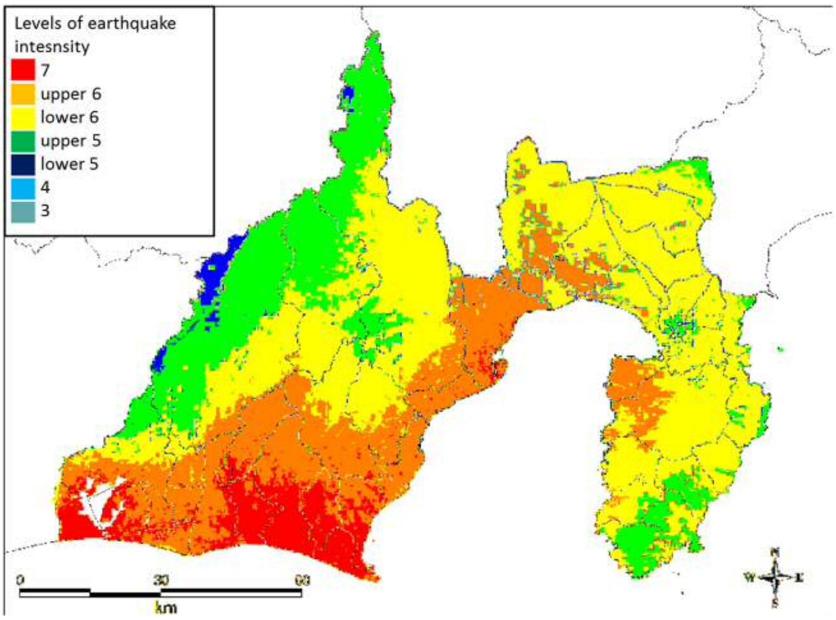

Figure 3　Seismic intensity distribution of the subjected area

3. SEISMIC PERFORMANCE EVALUATION OF WATER FACILITIES

Civil Structures

The seismic performance evaluation of civil structures was determined by reflecting the seismic detailed diagnosis conducted between 2013 and 2015, and the evaluation is based on the construction year and ground conditions to evaluate the seismic properties in earthquake level. Figure 4 shows the flow chart of the evaluation method for civil structures.

Structures diagnosed as not securing the seismic performance of level 2 are evaluated based on the seismic intensity distribution of Nankai megathrust earthquake. Undiagnosed structures were categorized into 4 groups based on the construction method, the ground conditions and foundation method, and by reflecting the earthquake scenarios of each area damage evaluation was conducted.

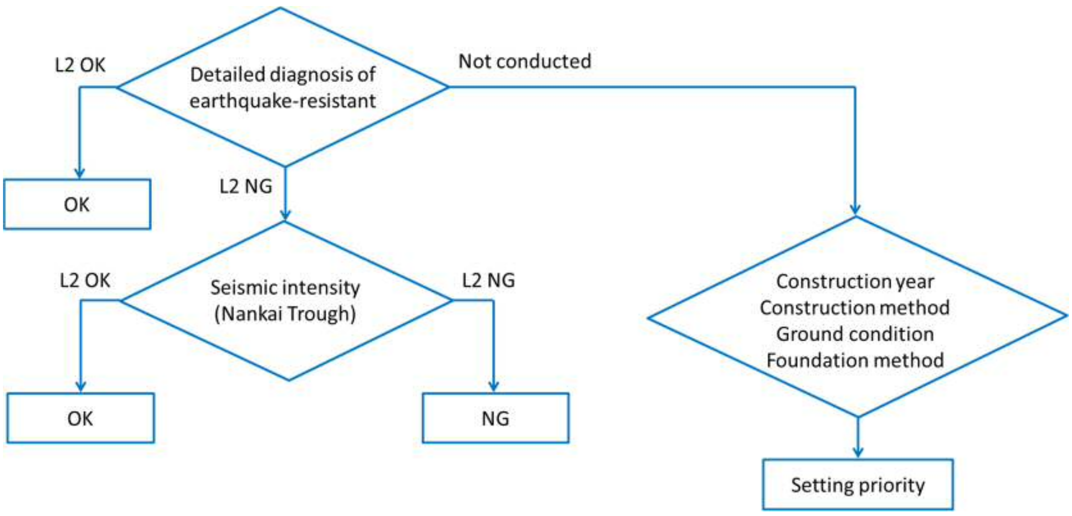

Figure 4　Flow chart of civil structure evaluation

Table 1 Earthquake-resistant estimation

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 good 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 good ground condition ・“Ⅲ”structures without good ground condition
4	Bad	There is a possibility getting damaged	・NG by seismic detailed diagnosis ・“Ⅱ” structures without good 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 capacity smaller 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 facilities and 40% of the purification facilities could not secure the seismic performance. Over 50 % of the water supply facilities and distribution facilities are not securing seismic performance due to the construction year, and the Nankai megathrust earthquake may severely damage numerous water facilities.

Water Pipes

Seismic performance of water pipes was evaluated 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（spot/km） : $R_m(v)$
- 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
- Standard 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, 1,566 water pipes were damaged and the breakage ratio was 0.585 spot/km. This is a ratio between the damage caused in Kobe and Nishinomiya city by the Great Hanshin Earthquake, and shall require a long recovery period.

The supply interruption rate for each region was calculated from the breakage ratio. The supply interruption rate was calculated by using the available water supply ratio and breakage ratio[3]. As a result, the total interruption rate was 50 %, which shall influence the water supply in wide range areas.

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)
1	45%	1192	597	0.32	1543
2	64%	338	172	0.49	362
3	55%	808	683	0.45	1315
4	25%	206	63	0.17	207
5	44%	77	23	0.29	49
6	67%	56	29	0.51	56
Total	50%	2677	1566	0.59	3532

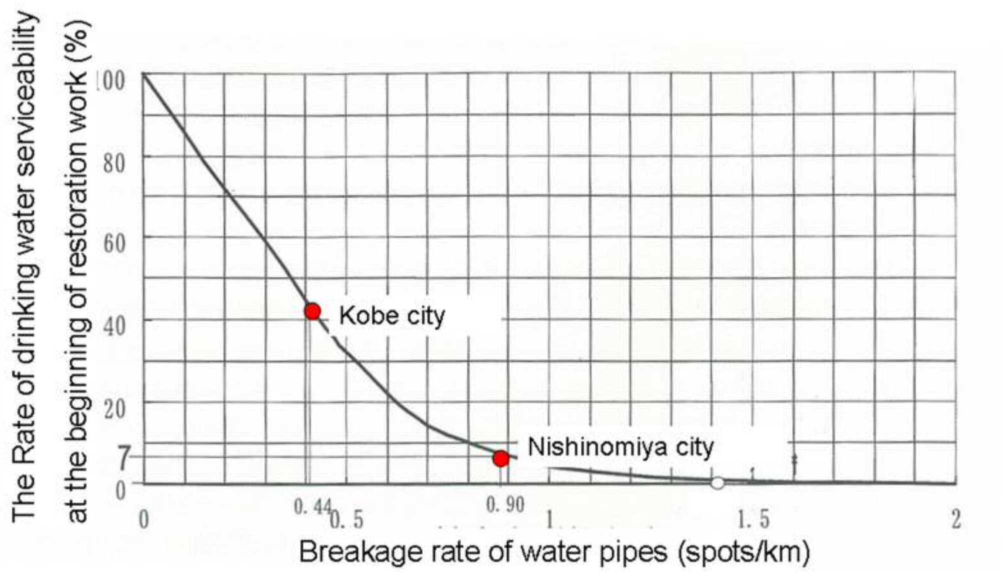

Figure 5 Rate of drinking-water serviceability at the beginning of restoration work[4]

4. EMERGENCY RESTORATION SIMULATION

Basic Policy

Emergency restoration term is predicted based on the results of water facilities. The supply interruption term is the main subject of water pipe emergency restoration, so it is assumed that the restoration term should be calculated by the damage of water pipes[4]. However, the damage prediction of main civil and architect facilities are also grave. Therefore, it is necessary to also consider the emergency restoration of purification stations.

Restoration Speed of Structures

The emergency restoration term of each water facility is determined from previous earthquake disasters. Table 3 shows the emergency restoration term of water facilities. The values consider only the emergency restoration and the repairing and the reinforcement are not included.

Table 3 Emergency restoration term of water facilities

Name of water faility		Restoration term (day)
Purification station	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 source		3
Distribution station		3
Pumping station		3

Restoration Speed of Water Pipes

Table 4 shows the restoration speed of water pipes of each diameter. The emergency restoration term of water pipes is calculated based on the restoration speed[4], and the restoration speed for pipes with diameter of over 700 mm is calculated using the "Earthquakes Countermeasure Manual Guidance"[4]

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

In this study, 70 emergency restoration squads were supposed to be sent to the damaged locations in the subjected area each day to restore water facilities. This number was calculated by the served population and the earthquake scale[6]. The number of restoration squads for each area was determined by the restoration term in ratio of each area against the total restoration term. The restoration shall start at the water intake stations, since the supplied water can't reach the households until the supply pipes as well as the purification stations are completely restored. Therefore, the water facilities shall be restored in order. Figure 6 shows the restoration step of water facilities.

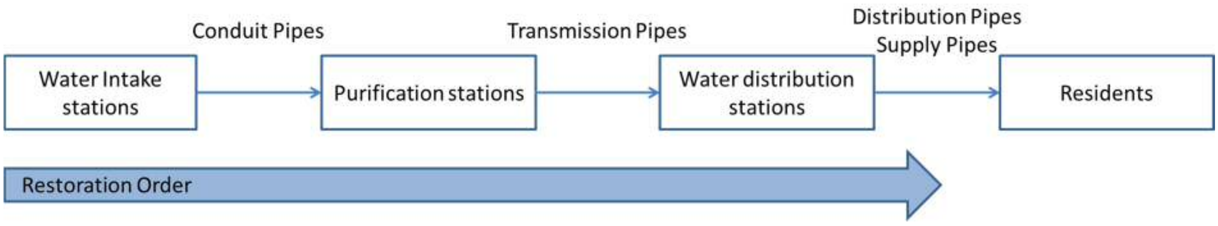

Figure 6 Restoration steps of water facilities

Result

It was 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 supply pipes when it is restored by the method. Target water supply is determined by the earthquake countermeasures of waterworks of the subject area. Then, the deficient term of emergency water supply is calculated in each area and it is assumed that water facilities started to be restored from the area that has longer deficient term. Further, the deficient term of emergency water supply is defined as the term 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 supply 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 is stable when the end of the supply pipes are restored.

Figure 8 shows the transition of target water supply and available water supply in 4 example areas, 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 restoration term of supply pipes and distribution pipes, and it gets damaged greatly. In area C, it takes a lot of time to recover conduit pipes and transmission pipes, but distribution pipes and supply pipes are restored in 2 weeks and necessary water supply are secured and the deficient term is shortest.

In this way, it was focused on the deficient term of emergency water supply and promotion of the earthquake resistance countermeasure from the longest deficient term.

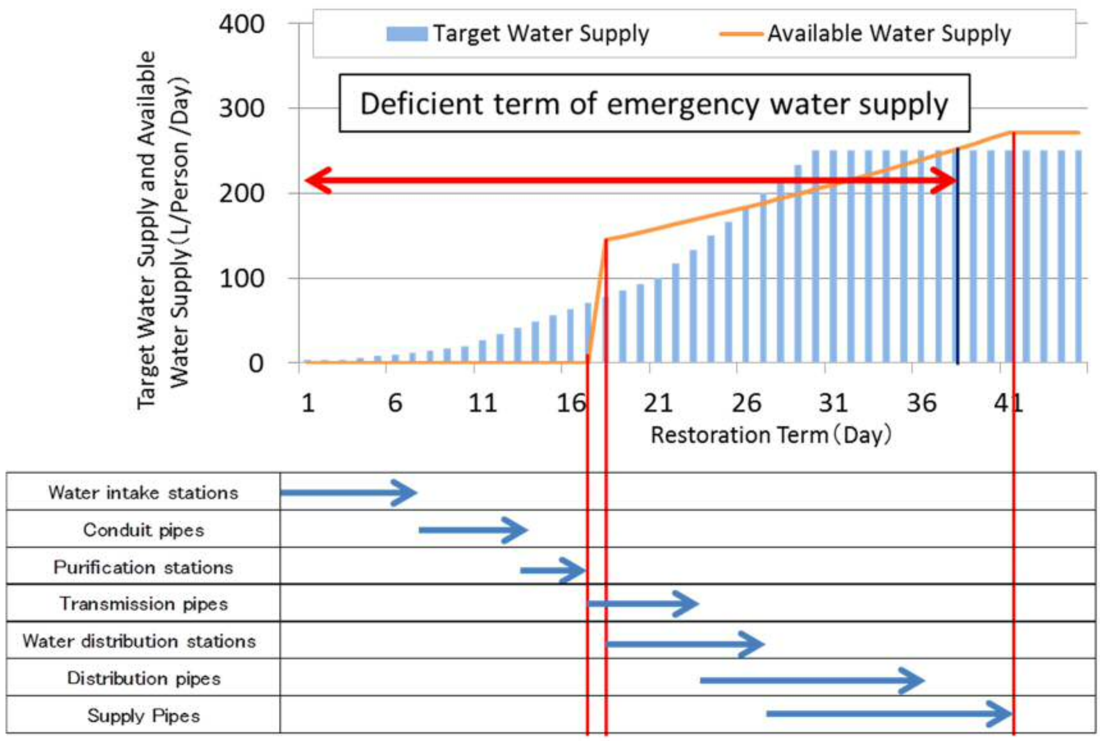

Figure 7 Deficient term of emergency water supply and restoration process

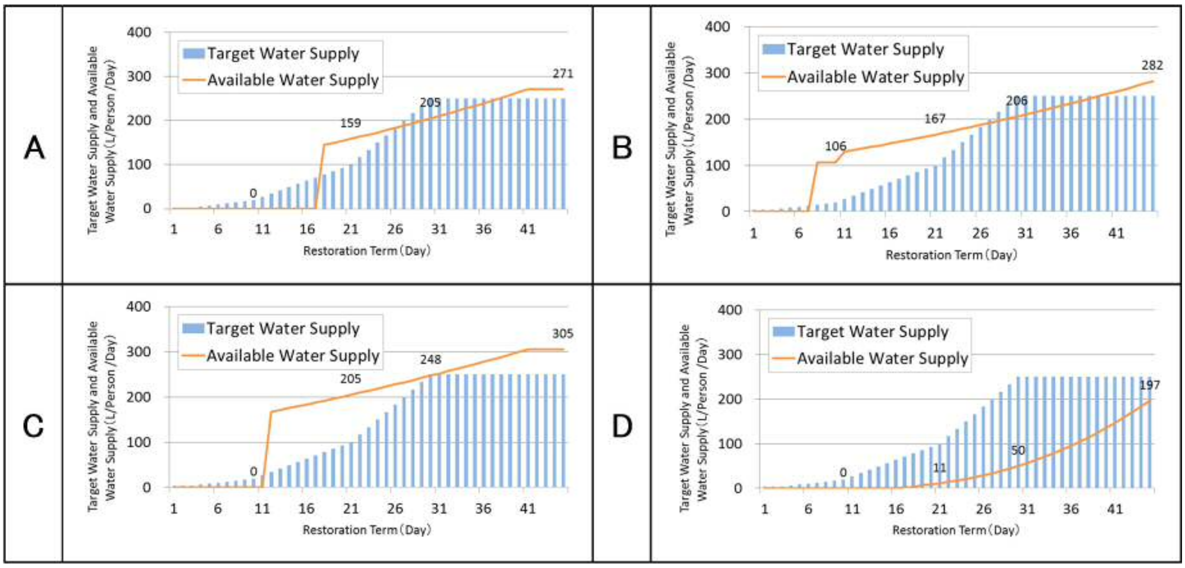

Figure 8 Transition of target water supply and available water supply in each area

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 supply pipes		
A	17	19	38	3	2
B	8	–	37	8	3
C	12	–	12	7	4
D	14	33	50	28	1

※ Restored in stages.

5. SETTING THE TARGET OF EARTHQUAKE-RESISTANT

It was mentioned that how to set the order in each area in preceding paragraph, but the deficit of water flow is 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 is hardly supply water when conduit and transmission pipes are damaged even if supply pipes are restored completely, conduit and transmission pipes should be restored to secure water supply. Therefore, it is considered the damage of conduit and transmission pipes needed to be reduced and it is securing 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 supply pipes are not restored completely and they can't afford enough water supply. Therefore, we need to take countermeasures of distribution and supply pipes to afford enough water supplies during this period.

Figure 10 shows restoration simulation after earthquake resistance in area A. It is assumed that 15% of conduit and transmission pipes and 10% of distribution and supply pipes are reinforced, 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 megathrust earthquake occurred.

Thus, it is considered the target of earthquake resistance should be set to secure necessary amount of water, and the earthquake resistance plan will be understandable for water users.

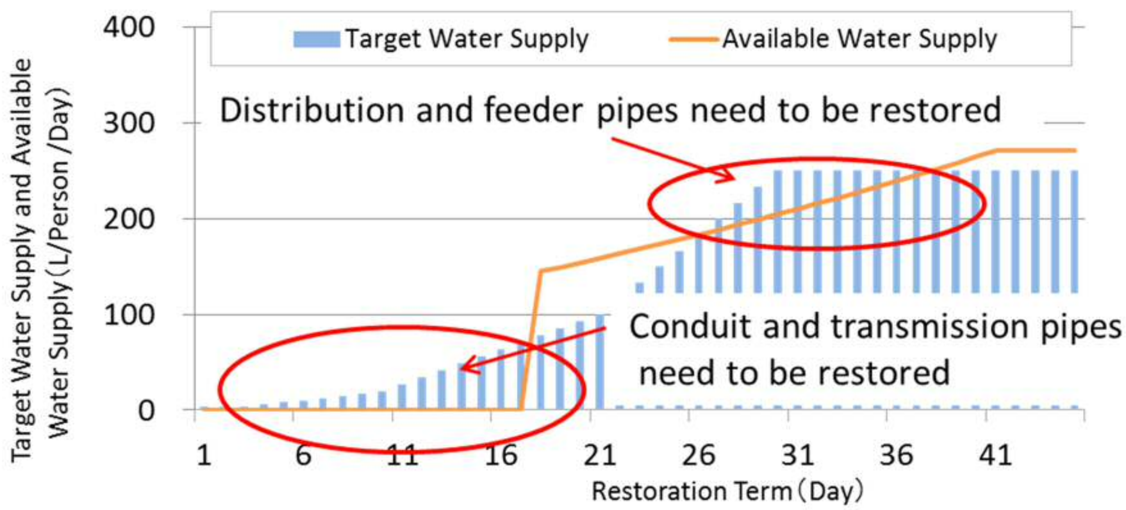

Figure 9 Restoration simulation before earthquake resistance in area A

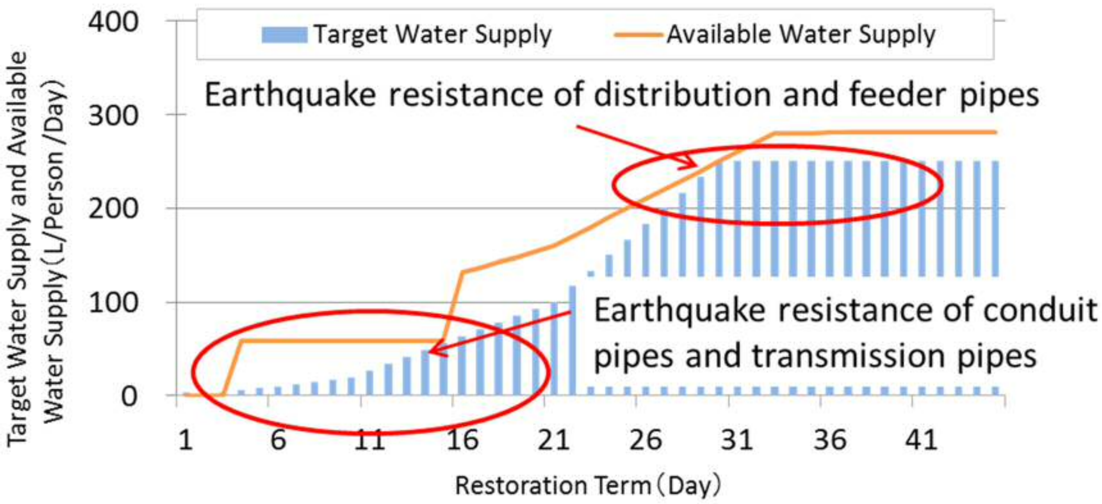

Figure 10　Restoration simulation after earthquake resistance in area A

6. CONCLUSION

This study focused on the restoration process of water flow for the priority evaluation of earthquake-resistance for each area to easily understand earthquake-resistant resets for the water users. The target for this study was a major city, but in case of small cities, the number of restoration groups is limited and expected many water facilities do not secure the seismic performance. Therefore, restoration simulation on small cities and investigations on the difference of restoration process between major and smaller cities are planned to be carried out in the future.

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