Damage of Sewage Plant by Tsunami

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SUMMARY:
This work describes a damage assessment of a sewage plant in Shizuoka city by next Tokai earthquake tsunami through numerical simulation. This plant is one of major plants in this city. A top of building of activated sludge tanks is open to citizens as a football field and appointed as a temporal evacuation building. Numerical simulation showed that this building is not destroyed by the earthquake and not inundated by the tsunami, based on the fault model by Central Disaster Management Council (2001). However, if the dislocation is twice the above value, this plant is inundated. Because the inundation depth is several-tens centi-meters, structures may not be destroyed. However, power facilities and the activated sludge tanks are under water. Thus, the sewage treatment becomes out of operation and it takes one year to recover. It is necessary to construct waterproof walls and doors to avoid such heavy damage.

Keywords: Tsunami damage, sewage plant, numerical simulation

1. INTRODUCTION

East Japan was attacked by a giant earthquake and tsunami on 11 March 2011. Because many sewage plants had located near coast, about 40 % of plants became out of operation by the tsunami in main damaged area. The damaged plants started simple sewage treatment within a few weeks, although a few years might be required for full restoration. Once a sewage plant is damaged, the influence is serious and it takes a long time to recover. Thus, a damage assessment should be conducted considering various uncertainness or possibilities.

This paper describes a damage assessment of a sewage plant in Shizuoka city, Tokai region, Japan. This estimation had been conducted before 11 March 2011 (Fujima et al., 2007), and new fault model near Tokai region is just under consideration by Central Disaster Management Council (CDMC) of Japan. Thus this may become old information soon. However, this estimation made a vulnerability of sewage plant against tsunami clear, and its validity was proved by the 2011 East Japan tsunami. This paper may provide the guide for assessment manner of sewage plant against tsunami.

2. DAMAGE BY EARTHQUAKE

2.1. Model Site

The location of the model site, Nakajima sewage plant is shown in Fig.1. Tokai region had been hit by tsunami repeatedly. Typical example is 1498 Meio-Tokai earthquake tsunami and 1854 Ansei-Tokai earthquake tsunami. Thus some measures were planed and conducted as preparations for next Tokai earthquake tsunami from 1970's. This sewage plant locates in a predicted fault area of next Tokai earthquake, and it faces the sea. Besides, this area surrounding the plant site had been inundated by 1854 Ansei-Tokai earthquake tsunami. Thus, Nakajima plant was constructed on the ground rising

2-2.5m, and it opened in 1985. However, it is one of major plants in Shizuoka city. Even in case that the center of Shizuoka city is saved from tsunami, if this plant is damaged, the citizens are affected by the damage of this plant.

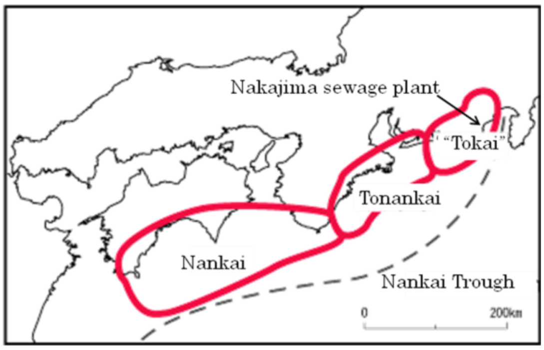

Figure 1. Location of model site (left: relation with Nankai trough, right: local map)

2.2. Damage of Building

At first, stability of the building of activated sludge tank (see Fig.2) was checked by a nonlinear earthquake response analysis. The top of the building is open to citizens as a football field and appointed as a temporal evacuation building for next Tokai tsunami. The effect on the ground of this site was checked using several proposed seismic wave models. The most influential model was selected for structure analysis. As the result, the maximum deformation of the building is 24cm as shown in Fig.3. The shear stress and bending axial force of all materials is less than the proof shear stress and ultimate curvature. The building is expected to be usable after the earthquake.

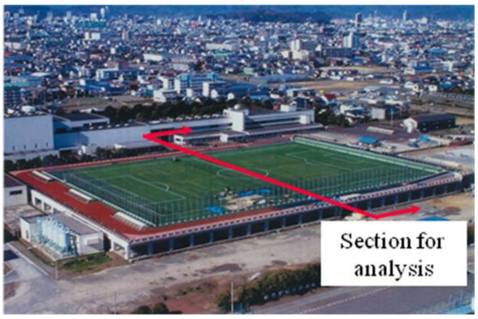

Figure 2. Building of activated sludge tank and section for structure analysis

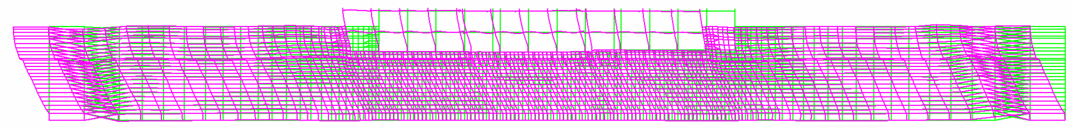

Figure 3. Estimated maximum deformation (maximum deformation =24cm)

2.3. Damage of Bank

Nakajima plant is protected from tsunami by bank at sea-side and river-side. The elevation of coastal and river bank is 7.13m and 6.8m from Tokyo Peil (T.P.), respectively. However, the plant locates just near the river-mouth, thus the ground consists of sandy soil, and it is possible to be liquefied by earthquake. Using N-value near Nakajima plant, the subsidence of crown height of sea-side bank is estimated 2m at the maximum. The river-side bank is expected not to be liquefied, however the subsidence is estimated as 0.6m. Thus, the height of coastal and river bank becomes 5.13m and 6.2m (T.P.), respectively, if subsidence is considered.

3. DAMAGE BY TSUNAMI

3.1. Numerical Conditions

3.1.1. Numerical Domain

The numerical domain and water depth in Region 1 is shown in Fig.4. The grid size is 1350m in Region 1. Region 2 whose grid size is 450m is nested in Region 1. Similar nesting technique is adopted five steps. The grid size and grid number is summarized in Table 1. The finest grid size is 2m in Region 6. The open data of CDMC is used for bathymetry in Region 1 to 4. The LiDAR data is used in Region 6. The data in region 5 is obtained by interpolation of data in region 4 and 6.

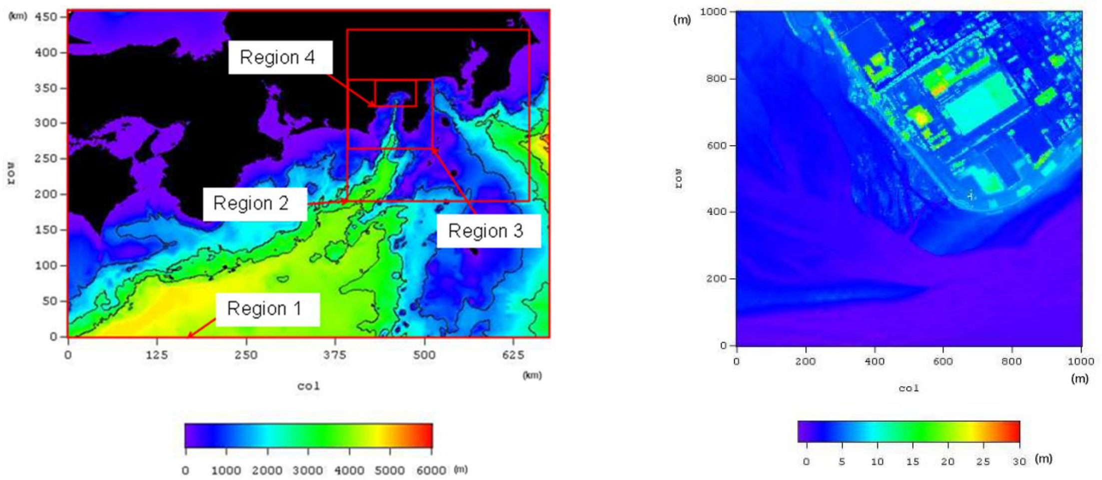

Figure 4. Numerical domain and nesting of Region 1 to 4 (left) and topographic data in region 6 (right)

Table 1. Grid size and grid number in Region 1 to 6

Region	Grid size (m)	Grid number in north-south direction	Grid number in east-west direction	Topography data
1	1,350	340	500	Open data of CDMC (UTM coordinate)
2	450	540	570	
3	150	690	780	
4	50	720	1,320	
5	10	500	600	Interpolation by Region 4 and 6(DEM)
6	2	1,000	1,000	LiDAR (DEM, DSM)

3.1.2. Modification of Topographic Data in Region 6

Basically, surface height of building is used as topographic data in Region 6 in order to consider detailed behaviour of tsunami in sewage plant. However, in case that tsunami is expected to intrude the building, elevation of first floor is replaced with original data. For example, the building of settling basins (see Fig. 2) has no wall at coastal side and opposite side; thus the elevation of the floor is used as ‘ground elevation’.

The subsidence of river and coastal bank is considered because of the result of 2.3. The subsidence of river and coastal bank is 0.6m and 2.0m, respectively. A river-mouth bar is assumed to be washed away by tsunami; namely sediments in river are erased.

3.1.3. Governing Equations and Other Conditions

The linear long wave theory is adopted as the governing equations in Region 1 to 3, and the nonlinear long wave theory in Region 4 to 6. The tidal level is assumed to be 0.86m, the mean monthly-highest water level of the nearest port to Nakajima sewage plant. The bottom friction is considered by using Manning’s friction law, and the roughness coefficient n=0.025.

3.2. Numerical Results

3.2.1. Effect of Tsunami Source Model

CDMC had provided three source models for future Tokai earthquake tsunami (2001). In addition, they had examined the combination with Tonankai or Nankai earthquake tsunami. We estimated tsunami height at the front of Nakajima sewage plant based on all source models of CDMC. However, an important difference was not appeared in all results. Thus the simplest source model is selected in this paper. The source model is shown in Fig.5.

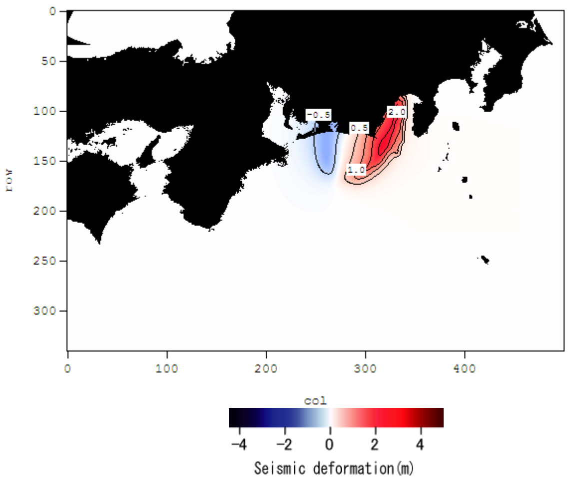

Figure 5. Tsunami source model

3.2.2. Numerical Results for the Model of Tokai Earthquake

The maximum inundation depth is shown in Fig.6. The highest water level at the coastal bank is about 5m; it is just below the subsided crown height of coastal bank. Thus the tsunami does not intrude into the sewage plant and city area. The right figure in Fig.6 shows the time history of inundation depth at the discharge gate of the sewage plant. Because the inundation depth at this point reaches 5m, there is a possibility that the tsunami flows into a tank from the discharge gate. Some measure is required to prevent such adverse current of seawater.

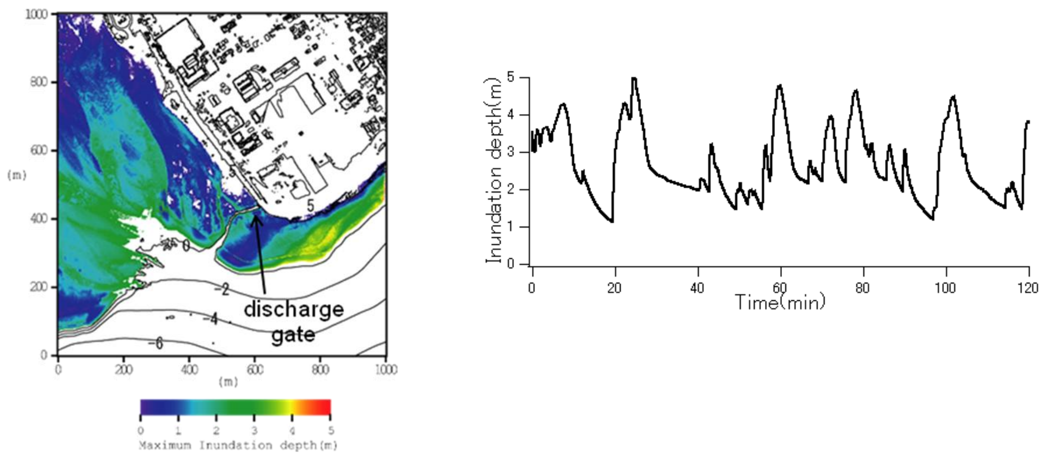

Figure 6. Maximum inundation depth (left) and time history of inundation depth (right) by CDMC(2001) model

3.2.3. Numerical Results for the extra-Model of Tokai Earthquake

The results of the former section indicate that Nakajima sewage plant is safe against earthquake and tsunami, if next Tokai earthquake and tsunami is equal to or smaller than CDMC model. However, the predicted tsunami height is close to the crown height of coastal bank, and it is possible that next tsunami is higher than the model. Thus we examine the inundation by the extra-model of Tokai earthquake. For simplicity, the initial tsunami elevation is assumed to be twice the CDMC (2001) model shown in Fig.5.

Figure 7 shows the situation of tsunami intrusion to Nakajima sewage plant considering two times initial water elevation. Figure 8 shows the maximum inundation depth. The right figure in Fig.8 shows the maximum inundation depth without considering the subsidence of coastal and river dike. The tsunami intrudes to the plant even if subsidence of dikes does not occur. However, inundation depth may become large if subsidence of dikes occurs.

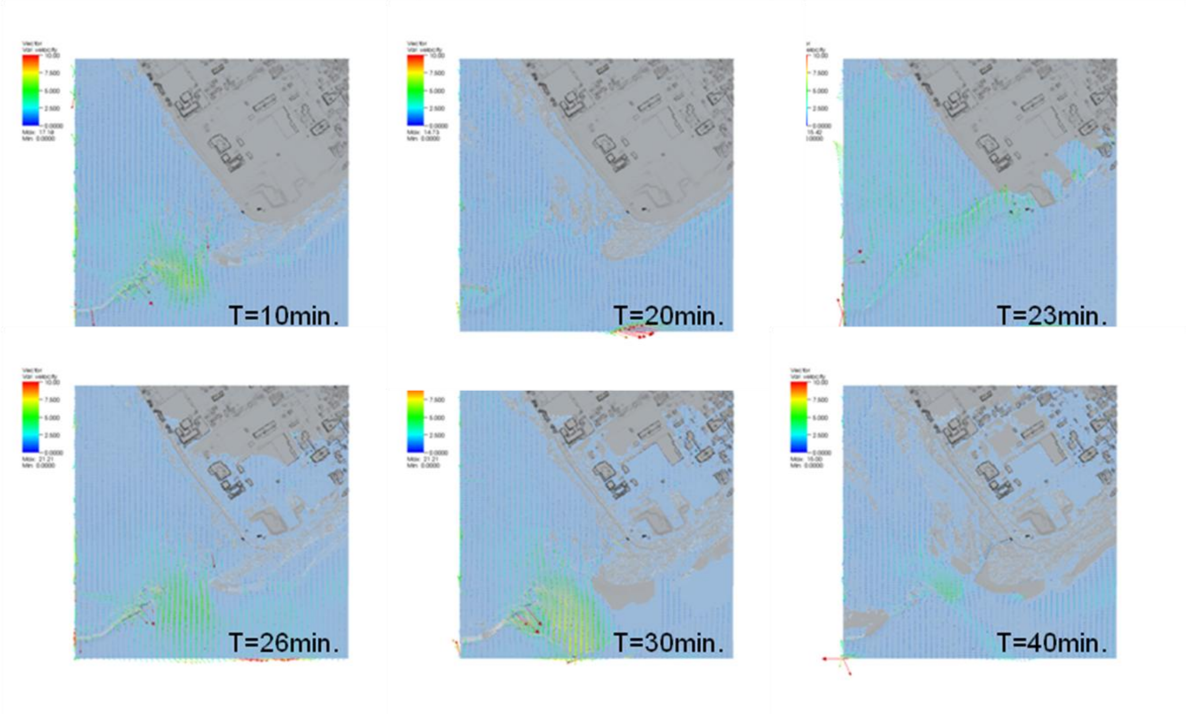

Figure 7. Tsunami inundation into the sewage plant by twice CDMC(2001) model

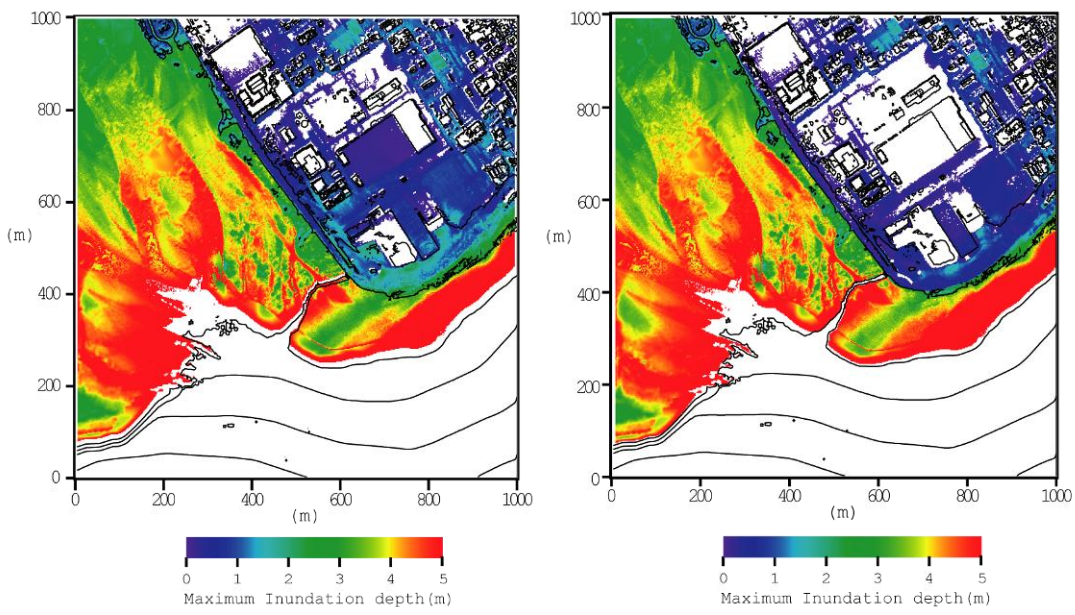

Figure 8. Maximum inundation depth by twice CDMC(2001) model (left: with subsidence, right: without subsidence of dike)

3.3. Damage and Restoration

If the next Tokai Earthquake is larger than the CDMC model, the tsunami intrudes to the sewage plant. In this section, the damage and restoration is discussed based on the numerical results by twice CDMC model.

As shown in the left figure in Fig.8, the sewage plant is inundated; however, the inundation depth is less than 1m. Thus, it is expected that buildings are not damaged. However, much of seawater, coastal sands and drifting debris are intruded to the settling basin and some underground rooms. In addition, electric equipments are submerged by seawater; most of them are not to be usable. Table 2 shows the summary of inundation situation; note that the maximum water level in the site is 5.6m (T.P.).

Table 3 shows the estimated amount of damage and restoration time. It is possible that more than one year is required for restoration of the sewage plant. This plant is the terminal sewage treatment plant, and has the biggest treatment capacity in this district. Even if this plant does not work perfectly, primary treatment by chlorine may be conducted and treated water may be drained by back-up power source. However, it is not evitable to lower the quality of treated water for more than one year.

Table 2. Inundation of facilities by twice CDMC model

facility	Criterion of water level not to be submerged (m, T.P.)	Submerged or not	Note
Building of pump for sewage settling basin	5.0	submerged	
Rainwater settling basin	5.0	submerged	Electric motors are safe.
Pump for rainwater	9.0	safe	
First settling basin	6.7	safe	Sludge pump is submerged.
Aeration tank	5.0	submerged	
Last settling basin	5.0	submerged	
Sterilization facility	5.0	submerged	
Sand filtration facility	5.0	submerged	
Gravity thickener	5.0	submerged	
Mechanical thickener	5.5	submerged	
Building for sludge treatment	4.7	submerged	
Sludge dehydrator	11.6	safe	
Sludge incinerator	4.6	submerged	
Blower facility	5.0	submerged	
Incoming and transforming equipment	5.0	submerged	
Central surveillance facility	9.5	safe	
Private power generation facility	5.0	submerged	
Electric equipment for sludge treatment	11.6	safe	
Electric power storage facility	5.0	submerged	
Wind power generation facility	4.6	submerged	Transformer and control console is submerged.
Ground equipment	4.4	submerged	

Table 3. Damage and restoration time by twice CDMC model

	Amount of damage		Restoration time
	Items	Amount (million JPY)	
Structure	Sludge disposal Cleanup	500 100	1 to over 3months
	subtotal	600	
Mechanical equipment	Pump for sewage settling basin Water treatment Blower Sludge treatment (including incinerator)	300 300 200 200	6 to over 12 months
	subtotal	1000	
Electric equipment	Incoming and transforming Private power generation Special power Operation Instrumentation Supervisory control	1200 200 300 1100 1000 2000	6 to over 12 months
	subtotal	5800	
Ground equipment	Gate, fence, planting	200	6 to over 12 months
Total		7,600	

4. CONCLUSIONS

The Nakajima sewage plant is safe against earthquake and tsunami if those are equal to or smaller than the CDMC model. However, there is only small margin of the tsunami and bank height. If the dislocation becomes twice CDMC model, this plant is inundated; the estimated amount damage is 7.6 billion JPY (600 billion dollars) and the restoration time is estimated 6 to more than 12 months. It is possible that the quality of treated water is lowered for more than one year. Once sewage plant is damaged by tsunami, the effect is serious and it takes a long time to recover. It is necessary to establish an extra protection and sewage-system continuity plan.

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