Chiaki NAKAMURA
Masaaki OZAKI

Japan Institute of Wastewater Engineering Technology

ASEISMIC MEASURES AND DAMAGE OF WASTEWATER FACILITIES IN THE GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI

ŚRODKI ZAPOBIEGAWCZE A SZKODY OCZYSZCZALNI ŚCIEKÓW PODCZAS WIELKIEGO TRZĘSIENIA WE WSCHODNIEJ JAPONII

Japonia, która jest znana z częstych trzęsień ziemi, promuje rozwój środków zapobiegających trzęsieniom ziemi, co wynika z niezliczonych doświadczeń katastrof naturalnych. Oczyszczalnie ścieków nie są wyjątkiem. Przedsięwzięto wiele działań mających zabezpieczyć oczyszczalnie przed skutkami trzęsień. Niemniej, we Wielkim Trzęsieniu we Wschodniej Japonii takie obiekty zostały uszkodzone przez nie mającą precedensu w skali falę tsunami. Z tego powodu, aby zdobyć wiedzę w oparciu o tę nie mającą porównania katastrofę, przeprowadziliśmy sondaż w władzach lokalnych dotkniętych obszarów, aby dowiedzieć się jakiego typu uszkodzenia nastąpiły i jakie były problemy z konwencjonalnymi środkami zapobiegawczymi przed trzęsieniami ziemi, tym samym dokonując przeglądu nowych środków zapobiegawczych odpornych na fale tsunami dla oczyszczalni ścieków.

1. Introduction

The Great East Japan Earthquake, which occurred in March 11, 2011, brought devastating damages to East Japan, or more specifically, the Kanto and Tohoku regions. The earthquake first occurred at the Pacific Ocean off the Tohoku region whose epicenter was at the Pacific Ocean off the Sanriku coast, followed by gigantic tsunami waves and frequent afterquakes.

Damage at wastewater facilities was tremendous, causing a lot of problems that had been never discussed. Most of sewage treatment plants and pump stations, which were concentrated into the coastal areas, were enormously damaged by tsunami waves. Moreover, liquefaction occurred at many landfill sites, leading to soil inflow in pipelines, which brought serious difficulty in residents' daily lives, such as stagnant wastewater or suspension of processing functions. The social impact of the earthquake and tsunami was truly immense.

In Japan, which is well known for frequent earthquakes, numerous massive earthquakes are predicted in the future. To prevent troubles ocurring at and after the Great East Japan Earthquake, we conducted a survey on disaster-stricken local governments. In this paper, we will report new aseismic and tsunami-resistant measures for wastewater facilities where measures for hardware are further strengthened, based on the survey results.

2. Overview of survey

2.1. Target

- Sewage treatment plants: All of 120 plants that were damaged by the Great East Japan Earthquake
- Pump stations: All of 112 stations that were damaged by the Great East Japan Earthquake
- Pipelines: 135 local governments that experienced damage in pipelines by the Great East Japan Earthquake

2.2. Details of survey

We asked each treatment plant or pump station about their facility classification (23 class for treatment plants and 5 for pump stations) as well as the degree of damage, type of damaged facility, cause of damage, distance from the coast, etc.

We also asked about the situation of damage and its details for pipelines by facility classification (pipe or manhole) and by damage cause (seismic motion, tsunami, liquefaction, etc.)

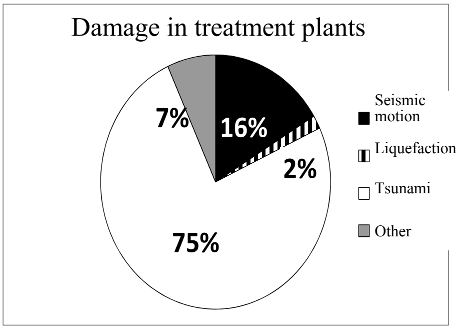
We sent our questionnaire and collected answers to it via email.

2.3. Collection rate, etc. (As of February 2012)

- Water treatment plants: 86/120 (72%), among which the rate for tsunami-hit plants are 16/86(19%).
- Pump stations: 75/112 (67%), among which the rate for tsunami-hit stations are 37/75 (49%).
- Pipelines: 96/135 (71%)
- Among which the rate of local governments suffered liquefaction in surrounding soil[1)]: 21/96 (22%)
- Among which the rate of local governments suffered liquefaction in backfilled areas[1)]: 61/96 (64%)

3. Characteristics of damage

Figure-1 shows the results of damages in multiple facilities at disaster-stricken treatment plants and pump stations classified by damage type based on survey results. Damage by tsunami covers more than a half of the total at both treatment plants and pump stations.



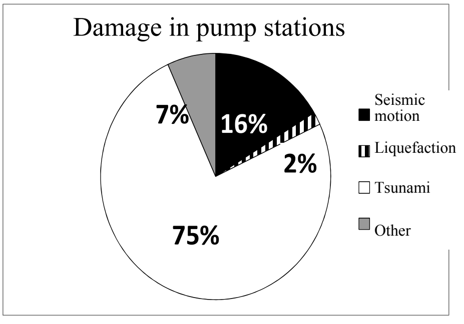
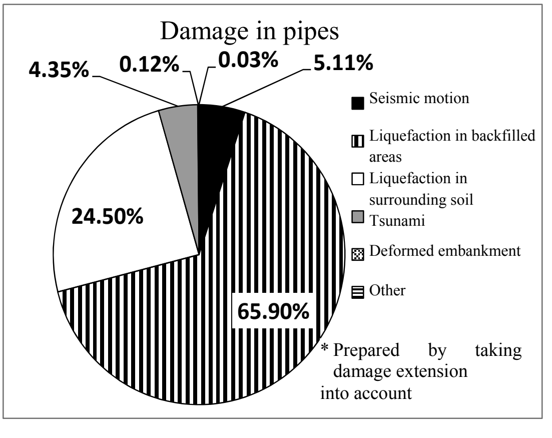


Fig. 1. Breakdown of damage in facilities at treatment plants and pump stations (multiple answers)

Rys.1. Zestawienie szkód w oczyszczalniach ścieków i przepompowniach

Among damages in pipes, liquefaction (in backfilled areas or surrounding soil) accounts for approximately 90% of the total, as shown in Figure-2. Such damage also covers approximately 70% of the total of damages in manholes.

Note that, however, damages in pipelines by tsunami were not clearly identified, since the situations in certain tsunami-hit areas had not been clearly investigated at the time of our survey.



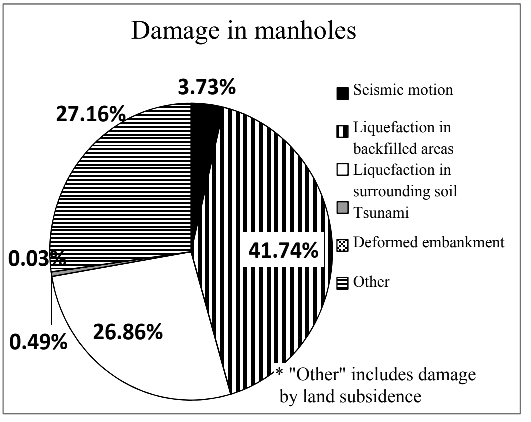


Fig. 2 Breakdown of damages in pipelines (multiple answers)

Rys. 2. Zestawienie szkód sieci wodociągowej

4. Situation of treatment plants damaged by tsunami and its trend analysis

There had been no cases of damage in wastewater facilities by tsunami in Japan until the Great East Japan Earthquake.

Here we describe situations of treatment plants tremendously damaged by tsunami last year and present its trend analysis results.

4.1. Situation of damage by tsunami

There are three causes of damages by tsunami: wave pressure, floating objects, and immersion.

Based on the survey results, we sorted out the causes of damages in facilities at treatment plants. As shown in Figure-3, "damage by immersion" accounts for 42% of the total.

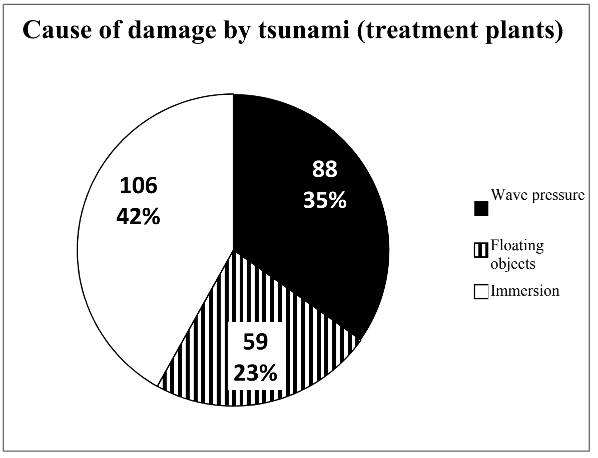


Fig.3 *Breakdown of cause of damage by tsunami in facilities at treatment plants (multiple answers)*

Rys. 3. *Zestawienie przyczyn uszkodzeń spowodowanych tsunami w różnych oczyszczalniach*

Figure 4 shows the number of treatment plants suspended, classified by whether or not hit by tsunami.

Focusing on the time to recover functions in treatment plants (operation suspension period), functions were recovered within one month at plants that had not been hit by tsunami, while it took more time for tsunami-hit plants to recover functions, though emergency repair were taken immediately.

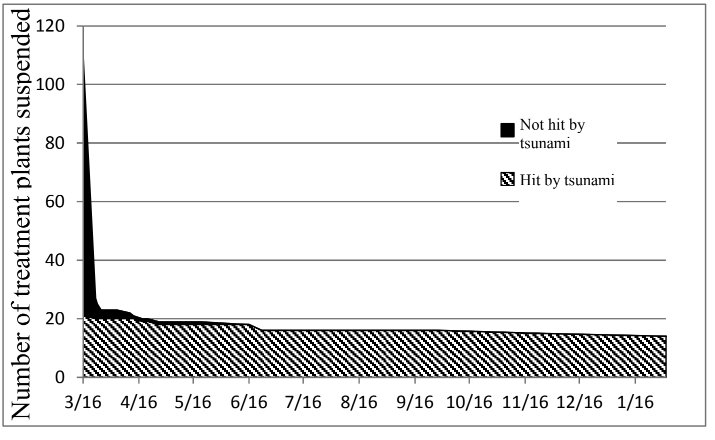


Fig. 4. *Comparison of the number of treatment plants suspended classified by whether or not hit by tsunami*

Rys. 4. *Zestawienie oczyszczalni ścieków, które zawiesiły działanie, sklasyfikowanych pod względem kontaktu z tsunami*

4.2. Trend analysis of damages by tsunami

4.2.1. Type of works damaged by tsunami

Figure-5 illustrates damages by tsunami, classified by type of works. The ratio of damage by tsunami tends to be higher than that by earthquake in electrical equipment.

Damages in electrical equipment by tsunami were mainly caused by immersion or lost of electrical rooms or control panels at sites.

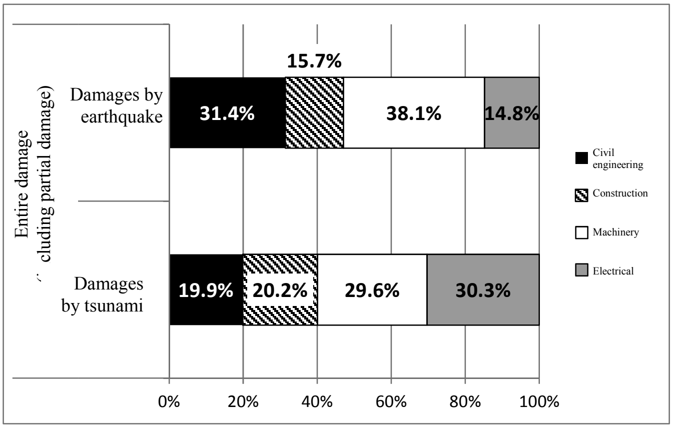


Fig. 5 *Comparison of damages classified by type of works between those by earthquake and tsunami*

Rys. 5. *Porównanie uszkodzeń sklasyfikowanych pod względem typu dotkniętych systemów przez tsunami lub trzęsienie*

4.2.2. Relationship between distance from the coast and damages

The relationship between the distance of the treatment plant sites from the coast and causes of damage in facilities in treatment plants (wave pressure, immersion, floating objects) are presented in Figure-6. From these results, it becomes clear that damage by wave pressure increases as the distance is shorter, while that by immersion or floating objects tends to increase as the distance is longer.

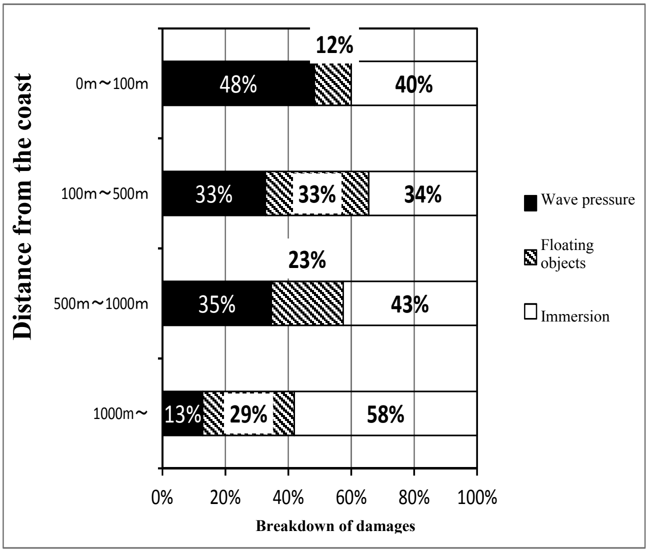


Fig. 6 Relationship between the distance from the coast and causes of damage (multiple answers)

Rys. 6. Związek pomiędzy odległością od wybrzeża a przyczynami uszkodzeń

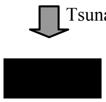
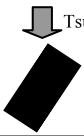
4.2.3. Trend of damage depending on direction of tsunami inflow and location of facilities

We classified the totally damaged facilities into three patterns according to the relationship between the tsunami inflow direction and location of buildings in treatment plants, as shown in Table-1.

The ratio of totally damaged facilities is the highest when the longitudinal direction of the building is orthogonal to the tsunami inflow direction, followed by the case when the building is oblique to the tsunami inflow direction. The ratio is lowest when the building is parallel to the tsunami inflow direction.

Tab. 1. Relationship between the tsunami inflow direction and location of buildings

Tab. 1. Związek pomiędzy kierunkiem fali tsunami a umiejscowieniem budynków

Location of buildings	Number of target facilities	Number of totally damaged facilities	Ratio of totally damaged facilities (%)
 Tsunami inflow direction The longitudinal direction of the building is **orthogonal** to the tsunami inflow direction	**17**	**7**	**41**
 Tsunami inflow direction The building is **oblique** to the tsunami inflow direction	**9**	**2**	**22**
 Tsunami inflow direction The longitudinal direction of the building is **parallel** to the tsunami inflow direction	**14**	**2**	**14**

4.2.4. Summary of damage trend analysis

It is confirmed that it takes longer time for treatment plants damaged by tsunami to restore, mainly because of suspended functions due to broken electrical equipment.

Electrical equipment is the core of operational functions: therefore it is highly probable that damage to it will easily lead to suspension of the entire treatment plants. Tsunami often causes immersion of the almost entire plant. Electrical equipment, which is especially vulnerable to immersion, is thus completely damaged at the time of tsunami, causing prolonged suspension of operations.

It is also necessary to review measures to prevent operation suspension considering the relationship between tsunami inflow directions and building locations, based on the trend of damage causes depending on the distance from the coast.

5. Situation of damage in pipelines by liquefaction in surrounding soil and its trend analysis

In the past earthquakes, damage in pipelines by liquefaction mainly occurred in backfilled areas, and various countermeasures had been taken. At the earthquake in 2011, it was confirmed that there was almost no damage in areas where a certain measures had been taken, which demonstrated effects of existing measures. But at the same time, liquefaction occurred in an extensive range of surrounding soil at the artificially changed areas, such as landfill sites (embankment areas) at Tokyo bay areas, or delta regions (old river channels), which brought unprecedentedly devastating damage to these areas. It was the very typical damage in pipelines in this earthquake.

Therefore, I think it is important to present the situation of damages in pipelines by liquefaction in surrounding soil and its trend analysis in this paper.

5.1. Situation of damage by liquefaction in surrounding soil

Among damages by liquefaction in surrounding soil, causes of damages in pipelines in Urayasu City, Chiba Prefecture are presented in Figure-7, since damages at this city were especially devastating. Among damages in pipes, those caused by sediment deposition accounts for 63.9%, almost two-thirds of the total; pipes were clogged with a large amount of sediment inflow, resulting in a suspension of pipe flow for a long period. Among damages in manholes, those caused by displaced manhole frames account for 46.0%.

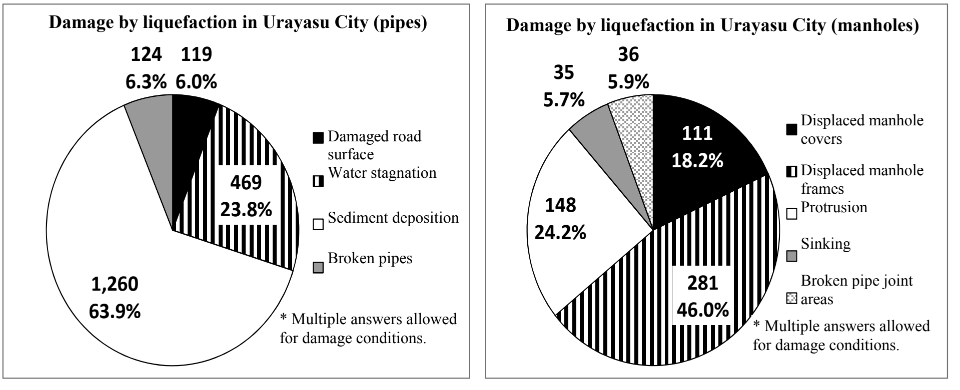


Fig. 7 Cause of damage in pipelines by liquefaction in Urayasu City (Multiple answers)

Rys. 7. Źródła uszkodzeń rurociągów przez powódź w mieście Urayasu

5.2. Trend analysis on damages by liquefaction in surrounding soil

5.2.1. Identification of path of sediment inflow into pipes

To understand the path of sediment inflow at the places damaged by sediment deposition, we checked the number of places where sediment deposited, broken collecting sewers, displaced manhole frames, broken pipes, broken pipe joints, as well as their positions, confirmed by TV cameras placed at four cities hit by liquefaction in surrounding soil. Figure-8 shows these results and their relationships.

Based on the sorted results, we confirmed the comparatively-higher linear approximation relationship between sediment deposition and broken collecting sewers/displaced manhole frames.

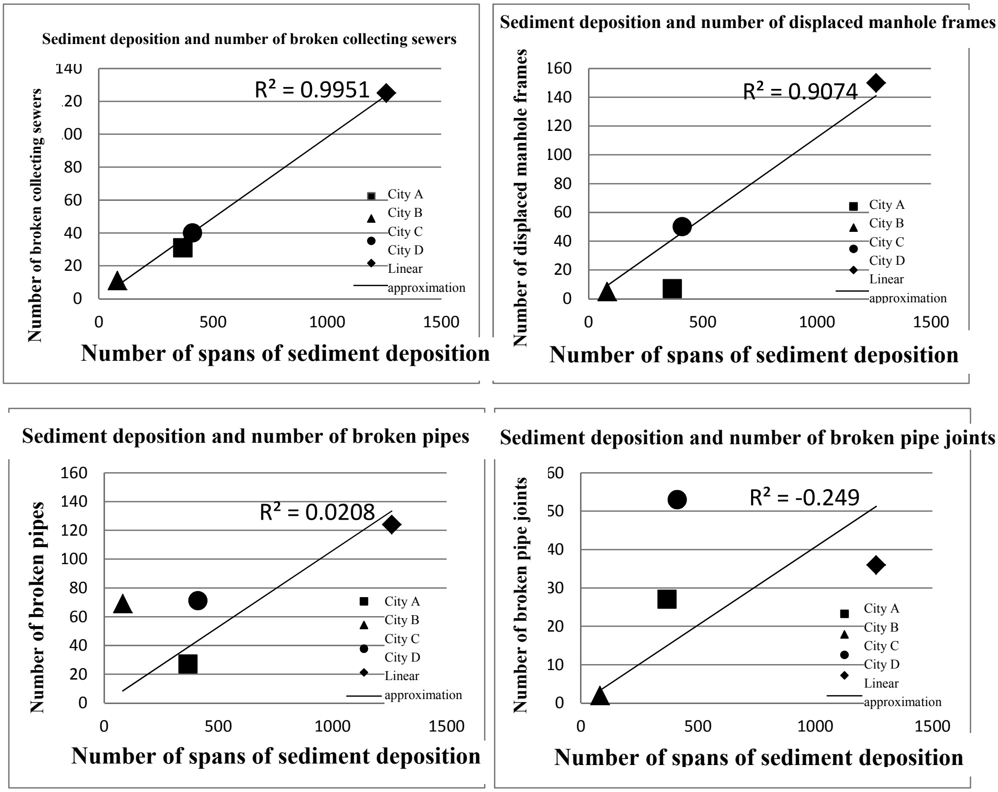


Fig. 8 Relationship between number of sediment deposition and that of each damage

Rys. 8. Związek pomiędzy ilością sedymentującego osadu a ilością uszkodzeń

5.2.2. Displaced manhole frames and types of manholes

We conducted a trend analysis of displaced manhole frames and types of manholes damaged in Urayasu City, Chiba Prefecture.

In Japan, assembled manholes[2)] were first launched in 1979. Since then, Japan Sewage Works Association has been promoting standardization of products toward those with higher waterproofness.

Urayasu City started construction of sewerage systems in 1970, when manholes having less unevenness at the assembly section were used, which leads to easy displacement between blocks. Figure-9 describes the relationship between the number of manholes constructed by various periods of time and the number of displaced manhole frames to calculate the damage ratio. Based on the results, it reveals that the high ratio of displaced manhole frames which were constructed in an earlier period.

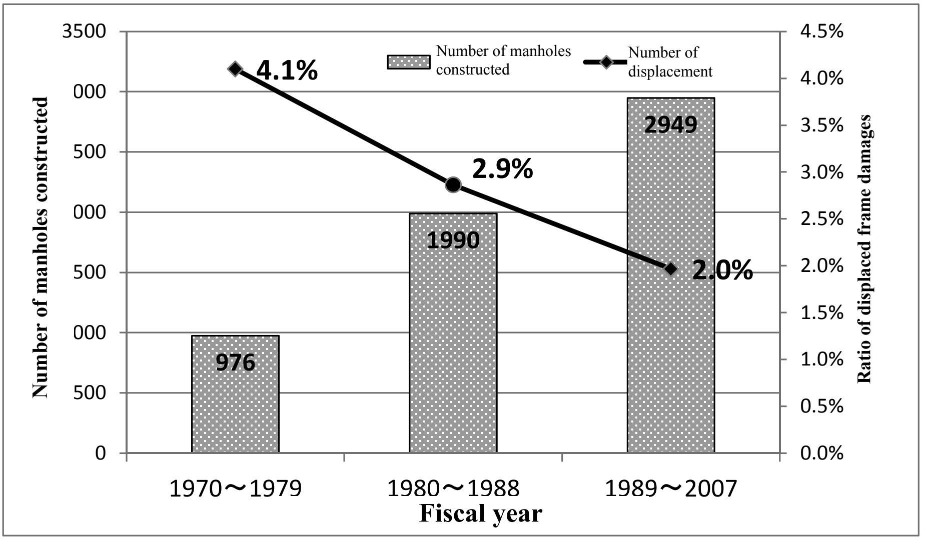


Fig. 9 *Relationship between the number of manholes constructed classified by periods of time and displaced frame damages*

Rys. 9. *Związek pomiędzy liczbą wybudowanych studzienek w klasyfikacji okresów czasu i udzkodzeniami przesunięcia studzienek*

5.2.3. Summary of damage trend analysis

Sedimentation deposition in pipelines due to liquefaction in surrounding soil was mainly caused by sedimentation inflow from broken collecting sewers and displaced manhole frames. Moreover, manholes that were constructed at an earlier period tend to cause displacement more easily, resulting in a sedimentation inflow at higher rate. Therefore, it is necessary to develop measures to prevent sedimentation inflow at areas where liquefaction in surrounding soil are assumed by predicting locations to be damaged at the time of liquefaction.

6. Views on future measures

6.1. Measures against tsunami

To prevent operation suspension for extended period of time by immersion resulted from tsunami at the largest level assumed, it is necessary to install or move electrical equipment at a higher floor, so as to provide waterproof measures for openings such as windows or doors of buildings for immersion prevention, as well as for the entire equipment.

At treatment plants near the coast, it is necessary to efficiently implement hardware measures considering immersion paths of floating objects, identify structures susceptible to have wave power even at the time of rarely occurring tsunami, as well as their locations. It is desirable to vigorously introduce tsunami simulation[3)] (Figure-10) by analysis, as it can be used for a quantitative verification method for assuming damage by tsunami and effects of measures.

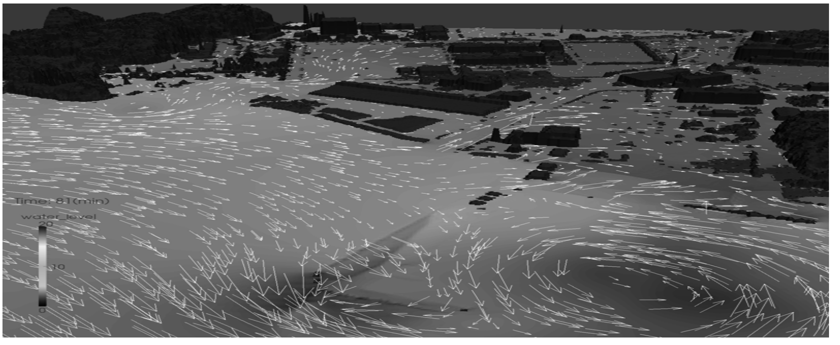


Fig. 10 Image of tsunami simulation

Rys. 10 Obraz symulacji tsunami

6.2. Measures against liquefaction in surrounding soil

To prevent inhibition of falling functions due to sedimentation inflow into pipelines, measures of securing flexibility and elasticity in joint areas at assemblies for old manholes, and in joints for collecting sewers are required for assumed sedimentation inflow areas. Figure-11 illustrates the concept of measures to prevent sedimentation inflow into pipelines.

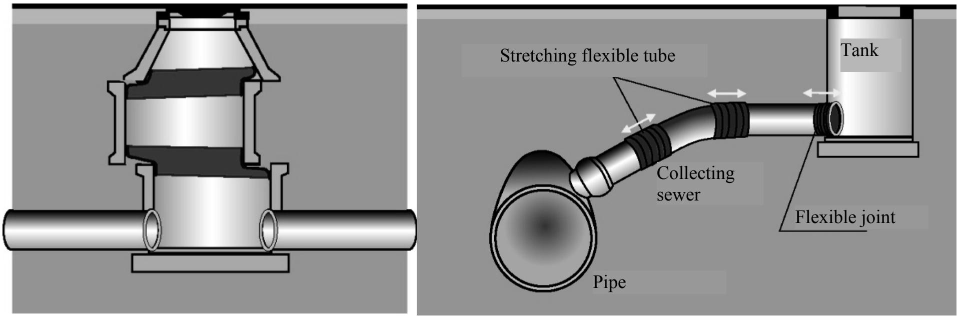


Fig. 11 Concept diagram of measures to prevent sedimentation inflow into pipelines

Rys. 11 Diagram Koncepcyjny środków zapobiegających wpływowi osadu do rurociągu

Note that, however, software measures based on BCP planning which aims for earlier recovery of functions, such as cleaning of pipelines after sedimentation inflow, are also necessary to strengthen, because it is difficult to completely prevent sedimentation inflow into pipelines.

6.3. Conclusion

In regions not damaged by the Great East Japan Earthquake and tsunami, it is also desired to study novel countermeasures against large-scale earthquake and tsunami assumed in the future, making most of knowledge acquired from this disaster.

References

[1] Japan Sewage Works Association, "Guidelines and Descriptions on Aseismic Measures for Sewage Facilities" pp136-138 (2006)

[2] Japan Sewage Works Association, Japan Sewage Works Association Standards A-11, "Reinforced concrete system manholes for sewage works"

[3] Japan Institute of Wastewater Engineering Technology, Data for a meeting of reviewing committee on basic plans for countermeasures against tsunami for wastewater facilities in Yokosuka City.