Measures for recovery against seismic damage to wastewater systems

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1. Introduction

Beginning with the Kushiro Offshore Earthquake in 1993, earthquakes have frequently damaged sewage treatment systems. The Hyogo-ken Nanbu Earthquake of January 1995 and the Niigata-ken Chuetsu Earthquake of October 2004 inflicted particularly severe damage on wastewater systems, either shutting down their treatment systems or severely damaging their pipelines. As the Hyogo-ken Nanbu Earthquake and the Niigata-ken Chuetsu Earthquake caused such serious damage to people's homes and to the social infrastructure, residents were forced to spend long periods of time evacuated from their homes. Damage to sewage treatment systems by these two earthquakes halted their operations, causing polluted water to flow directly into public bodies of water. This report describes (1) the characteristics of the damage caused by these two earthquakes, (2) measures taken until their wastewater systems were restored, (3) methods of providing support until the restoration of their functions halted by earthquake damage, and (4) the toilet problem.

2. Scale of the Hyogo-ken Nanbu Earthquake and the Niigata-ken Chuetsu Earthquake and the characteristics of the damages

The Hyogo-ken Nanbu Earthquake, a magnitude 7.2 earthquake with maximum seismic intensity of 7, occurred early in the early morning on January 17, 1995. It inflicted extremely severe damage, killing 6,308 people, injuring 43,177, and totally destroying 100,302 homes. Damage to sewage systems by this earthquake effected the treatment operation at 8 plants and damaged an additional 43 treatment plants. It also damaged 56 pumping stations and a total of 162 km of pipelines.

The Niigata-ken Chuetsu Earthquake, a magnitude 7.8 earthquake with maximum seismic intensity of 7, occurred in the evening on October 23, 2004, killing 59 people, injuring 4,805, and totally destroying 3,175 homes. And the quake caused landslides and soil-collapse introducing damages on roads and railways throughout the effected region. In 2004 prior to this quake, large-scale flooding occurred in the Niigata Prefecture region on July 13, and abnormally heavy rainfall followed during the summer and autumn as a record number of 10 typhoons crossed the Japanese Archipelago. Therefore, where the topography was originally vulnerable to sliding, the rain loosened the ground, so that when this earthquake occurred, it caused soil to collapse at many locations. In addition to

sewage systems, it damaged lifelines such as electric power lines, gas mains, water mains, telephone lines, and the cell phone and internet infrastructures. And because telephone calls were made to Niigata Prefecture from throughout Japan, communication systems were congested, restricting ingoing communications. And communication cables and detour roads through the mountains were also damaged, isolating some municipalities from outside information. Cell phone systems that had been considered to be highly disaster resistant since the Hyogo-ken Nanbu Earthquake Disaster, were unusable over a wide area as relay stations stopped it's functioning so they could no longer handle calls. This occurred typically near the epicenter, relay station equipment was damaged and the power was cut off and batteries installed and charged to maintain the functions of relay stations during emergences were usable for only one day due to the flood of incoming phone calls. Damage to sewage treatment plants by this earthquake shut down 1 treatment plant and damaged 6 others. It damaged 6 pumping stations, obstructing the water supply functions of 2 of these. A total of 152.1km of pipeline were damaged, and problems were found at the locations of 2,506 manholes.

Damage to sewers differed greatly between the Hyogo-ken Nanbu Earthquake and the Niigata-ken Chuetsu Earthquake. The Hyogo-ken Nanbu Earthquake caused permanent strain of the ground that shifted pipelines and its earthquake motion caused cracking, but a large part of the damage by the Niigata-ken Chuetsu Earthquake was lifting up of pipes and manholes by liquefaction of backfill soil around pipelines. The lifting up of manholes blocked traffic. Damage to the sewers caused problem for draining from homes.

Photo1. A lift-uped manhole in Niigata-ken Chuetsu Earthquake

3. Restoration of the damage

In Kobe City that was the largest city to suffer severe damage during the Hyogo-ken Nanbu Earthquake, as the office building servicing for the Sewage Works Bureau was heavily damaged including data storage area, they had to the recovering works of the systems without major data

assistance in the initial phase. As a result, even though there had been pipeline data in digital conditions, it was unusable after quake due to under knocked off building, so that even if information about damage to complex pipeline networks coming to the restoration work center, they could not assess the degree of impact. Fortunately, a consultant company had stored copies of the original data. Besides luckily the City of Nagoya had adopted the same system, it was possible to use the Nagoya City System to print out the required data needed to perform the restoration works.

Even though the wastewater system had been damaged, it had to be quickly restored so it could resume its role as a lifeline. But it is not easy to identify the exact damaged locations in wastewater systems. It is often possible to visually confirm the state of damages to sewage treatment plants, but it is actually difficult to find out damages of sewers without interior inspections with TV cameras. Clarifying the state of damage and considering countermeasures is the first action that must be taken. It is, therefore, important to be able to mobilize a certain number of responsible employees. After the Hyogo-ken Nanbu Earthquake, it was not easy to gather staff, because of the extremely large scale of the damage it caused. Table 1 shows how the staff gathered.

Table1. Staff gathering conditions after Hyogo-ken Naubu Earthquake

City name	Staff number	within 1 hour		Within 6 hours		Within 12hours		Within 24 hours		Within 3 days	
Koube	-	-		-		-		-		-	
Ashiya	65	9	14%	23	35%	25	38%	27	42%	35	54%
Nishinimoya	191	-		-		-		124	65%	176	92%
Takarazuka	70	2	3%	50	71%	51	73%	52	74%	66	94%
Amagasaki	234	3	1%	74	32%	84	36%	84	36%	102	44%
Kawanishi	66	-		57	86%	-		-		-	
Itami	54	41	76%	41	76%	41	76%	47	87%	49	91%
Akashi	147	5	3%	117	80%	123	84%	123	84%	142	97%
Toyonaka	127	5	4%	84	66%	90	71%	90	71%	124	98%

The Higashi-nada Treatment Plant in Kobe City was damaged extremely by the earthquake, which not only cut off feeding wastewater to the treatment plant from its pumping station, but also damaged its main treatment system so it no longer functioned. Other treatment plants were also damaged, but on regarding the degree of damages and impact to environment, restoration of the Higashi-nada Treatment Plant was an extremely important. As the route linking this treatment plant with its pumping station was intersected with a canal, this canal can be used as a temporary settlement pond with enclosing sheet piles, preventing serious deterioration of the quality of the water in surrounding bodies of water. This measure was taken for 100 days.

A major cause of damage to the treatment systems in the Higashi-nada Plant was the destruction of piles caused by lateral flow triggered by liquefaction of the sandy ground in a reclaimed land area. To identify this cause required a great deal of time-consuming work, but once its results were obtained, measures to restore the systems were taken.

The Niigata-ken Chuetsu Earthquake shut down the Horinouchi Treatment Plant of a river basin sewerage system in Niigata Prefecture, allowing polluted water flowing into the plant to overflow, inundating with incoming wastewater around the plant. This was caused by damage to the inlet, but the treatment systems were also severely damaged as well. As emergency measures, a temporary settlement pond and a disinfection plant were installed to prevent the discharge of untreated polluted water to nearby river.

Photo2.A temporary settlement pond and a disinfection plant in Horinouchi Treatment Plant

4. Problems providing assistance

Following the Hyogo-ken Nanbu Earthquake, assistance with restoration activities was provided to severely damage regions, mainly from large cities. Aware of the need for fundamental initiatives as a result of this experience, the Japan Sewage Works Association prepared Rules for assistance dealing with damage to sewage systems. Based on these rules, systems to provide support were established by dividing the country into six blocks. For ordinance-designated cities, another rule requiring mutual support by these cities was enacted.

When the later Niigata-ken Chuetsu Earthquake occurred, it was learned that when a municipality struck by a disaster requested assistance under this rule, supported bodies bore a specified cost burden including travel expenses and overtime pay for their employees, resulting in delayed requests for assistance from municipalities concerned about the payment of these costs. In fact, supporting organizations carried out the cost burden, so that finally wide area support was provided. Based on such experiences, the present support rules have been revised.

Under the present assistance procedure, a municipality with earthquake damage requests assistance within its block. When it is difficult for only the block to respond, the block requests assistance from the national government that responds by establishing a liaison office for seismic damage recovery.

This office assists the city where the disaster has occurred by coordinating efforts among the NILIM, Japan Sewage Works Agency, ordinance-designated cities, and related industries.

5. Toilet problems

The availability of toilets is a problem that appears immediately after earthquake damage has occurred. It is a tragedy when existing toilets cannot be used normally at evacuation sites where large numbers of people have gathered. Toilets are unusable in cases where water needed to flush them cannot be obtained or when the wastewater system is damaged so that it cannot remove human excreta from the toilets. In such cases, temporary toilets are installed, but if enough temporary toilets cannot be obtained, serious sanitary problems occur at the same time as the residents who have been impacted by the disaster are forced to endure even heavier mental and physical burdens.

After the Hyogo-ken Nanbu Earthquake, people whose homes were knocked down or burned down, whose supplies of electricity, water, etc. were cut off, or who could not remain in their homes because of fear of aftershocks, gathered at evacuation sites. Records show that at the peak point six days after the earthquake on January 23, 1995, there were 316,678 evacuees at 1,153 evacuation sites. People were evacuated to places like schools, gymnasiums, and parks.

There are toilets in public facilities of these kinds, but because the numbers of toilets were not set premised on their evacuee capacity and it was impossible to obtain water to flush them, they quickly became unusable after being used a few times. It is reported that because they could not handle the demand for toilet use, they were soon plugged with large quantities of excreta. Temporary toilets were installed beginning on January 18 the day after the earthquake, and on January 19, only 230, a number far from adequate, could be obtained. According to a survey carried out on January 24, the problem was still unresolved, as temporary toilets had only been installed at 2,488 locations, that was 45% of the locations they were needed. Later, temporary toilets were supplied that was owned by construction companies, providing 1 toilet for every 60 people at the evacuation sites. Even though enough number of temporally toilets were supplied with roads into the disaster region continuing to be seriously congested, it was not easy to transport temporary toilets from outside the region. In parks and athletic fields at schools, holes were excavated on the ground and used as emergency toilets, but they were unusable within a few days due to limited capacity.

When a disaster has occurred, food and water are considered to be priority, but ensuring sanitary toilet facilities were an even more important issue. Since then, a variety of emergency toilets have been developed, but toilets made using manholes have been very popular.

Based on experience gained from the Hyogo-ken Nanbu Earthquake, the following concept of handling excreta during disasters has been established. The top priority is taking advance measures to ensure that flush toilets can be used. Substitute measures are taken to cover the period until these flush toilets are usable. One thing that is essential to guarantee that flush toilets can be used is ensuring a supply of toilet water. This can be done by using water in pools at evacuation sites, using treated wastewater, using stored rainwater, and transporting water from the ocean, marshes, or rivers. At evacuation sites, water supply and water drainage systems must be seismically retrofitted in advance.

At the same time as the required numbers of conventional temporary toilets are provided, full scale preparations are being taken to use sewage system facilities to introduce new temporary toilets as full-scale disaster measures. Special manhole covers are introduced at the same time as manholes and covers are installed in parks and other evacuation sites where they can be used immediately when a disaster occurs, so that temporary toilets linked to sewage systems and manholes can be easily converted to toilets.

When the Niigata-ken Chuetsu Earthquake occurred, fortunately, with the cooperation of the construction companies, it was possible to supply a sufficient number of temporary toilets relatively quickly, so toilets were not a serious problem. But it has been reported that problems remained; the removal of the temporary toilets for example.

6. Conclusion

Earthquake damage to sewage systems directly links to toilet problems, causing serious problems following earthquakes. Large earthquakes that have occurred during the past ten years have provided considerable knowledge and experience including the characteristics of their damage, restoration methods, methods of gaining support from the surroundings, and toilet measures. While still not completed, measures to protect sewage systems from earthquake are progressing based on lessons learned in this way. It is predicted that a large earthquake will strike Tokyo in the future, requiring the development and improvement of technologies to perform seismic retrofitting and to take post-earthquake measures.

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Hyougo-ken Nanbu Earthquake and Niigata-ken Chuetu Earthquake

	Hyougo-ken Naubu	Niigata-ken Chuetu
Occurrence	January 17, 1995	October 23, 2004
Magnitude	7.2	6.8
Maximum accelation gal	818	1715
Loss of lives	6,308	59
Injured people	43,177	4,805
Damaged houses	436,414	121,613
Operatinal problemed STPs	8	1
Damaged STPs	51	6
Damaged PSs	56	6
Damaged sewers km	162	152

Typical damages to STPs:

- Damages in influent channel to STPs
- Damages to treatment plant structures
- Shutdown of operations
- Leakage or discharge of untreated wastewater to public water bodies

Measures against damages and shutdowns of operations of STPs

- Quick visual checks of damaging conditions
- Planning for recovery works
- Prevention of raw wastewater discharge;
  - Quick construction of temporary sedimentation ponds and disinfection facilities
- Repair or rehabilitation of some facilities
- Resuming of operations

- Restriction of discharge to sewers

Lessons from Higasinada introduced quick actions to Horinouchi

- Higasinada STP (1995)
  - Three weeks for starting temporary sedimentation
- Horinouchi STP (2004)
  - One week for starting temporary sedimentation
    - Experience teaches:
      - Quick assistance of JS to recovery works
      - Manual books for EQ damaging recovery after Hyougo EQ

Preparation for future; Long term measures for STPs

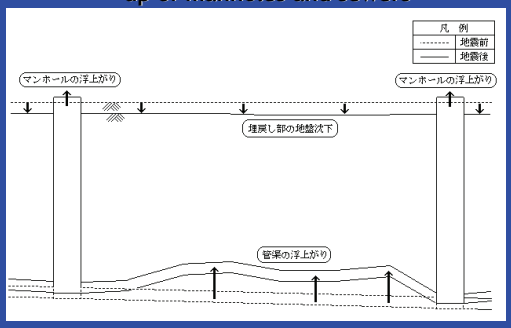
- Seismic proofing of existing facilities
- Reduction of damages as planning solutions
  - Networking of STPs
  - Multiple trunk-sewers
- STPs; high reliable evacuation centers

Typical damages to sewers

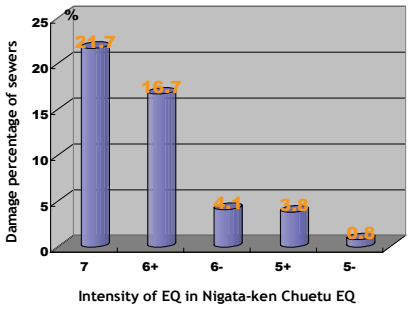
- Hyougo-ken Nanbu EQ:
  - Difficulty of finding of damages in sewers
  - Cracks caused by shaking of manholes and permanent strains of grounds
  - Relatively small damage-ratio: Ave.1.7%, Max.9.7%
- Niigata-ken Chuetu EQ:
  - Surfaced up of manholes and lifted up of sewers
  - Sinking of ground surfaces six months later
  - High damage-ratio: Ave. 4.6%, Max. 21.7%

Typical damage types in Niigata-ken Chuetu EQ

Liquefaction of backfilled sand caused floating up of manholes and sewers



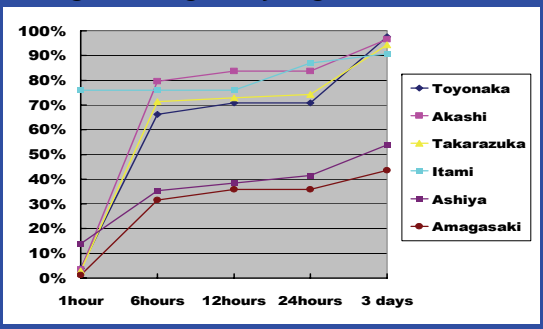
Intensity and damage ratio



Problem in recovery works

- Shortage of manpower and experiences:
  - Sewage work staff was inputted to rescue works or water works recoveries
  - Difficulty of full-staff gathering
  - No experience of quake disaster
- Functional incompetence of telecommunication means:
  - Telephone, facsimile, and mobile were dysfunctional
  - High traffics of signals or damages of infrastructure

Staff gathering in Hyougo-ken Nanbu EQ



Assistance providing from outside

- No detail information to central government offices
- Dispatch of an advance research party:
  - Selected member from HQ of MLIT, NILIM ,PWRI, & JS
- Setting of emergency headquarter office in disaster area:
  - Coordination among central government offices, prefecture offices, local governments, and related aggregate cooperations
- Recovery-work assistances;
  - damage surveys and recovery work preparations
- Contract based sewer-inspection worker gathering from all Japan
- Rules for assistance advocated by Japan Sewage Works Association—after Hyougo EQ:
  - Six block systems
  - Cost payment by requester side----------?

Toilet problem;

Toilet can not use due to lacking of enough flushing water and damages of wastewater systems

- Evacuation center;
  - Lacking of flushing water
  - Small number of toilets to many evacuee in a evacuation center
  - Small number of stocks of temporally toilets
  - Difficulty of smooth transportation of toilets
  - Lack of understanding of importance of toilet
- Residence;
  - Limited use of water for toilet flushing
  - Carrying water to residence is hard work
  - Repair works of sewers and laterals

Conclusions

- Quick assistance is the key to quick recovery;
  - Lesson from Hyougo-ken Nanbu EQ worked to recover from damages in Niigata-ken Chuetu EQ
  - Emergency HQ office in disaster site worked effectively
- Measures against STPs shutdown;
  - Construction of temporally sedimentation tanks and disinfections for prevention of epidemic
  - Restriction of discharge to sewer systems (is possible?)
- Deferent type of damages to sewers in Niigata-ken Chuetu EQ;
  - High ratio of damage in 6+ intensity and over
  - Sewer damage blocked toilet use
- Wastewater systems are the first priority lifelines