CHARACTERISTIC FEATURES OF DAMAGE TO THE PUBLIC SEWERAGE SYSTEMS IN THE HANSHIN AREA

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ABSTRACT

Damage to the public sewerage systems for six cities in the Hanshin area due to the 1995 Hyogoken-Nanbu earthquake was summarized as 140 km pipelines, 19 treatment plants and 32 pumping stations. Characteristic features of the damage compared to those in past earthquakes were as follows: 1) distribution of damaged pipelines was concentrated both in liquefied zones of the coastal area and in an area surrounded by two faults, 2) three large concrete pipelines were heavily cracked longitudinally, 3) internal concrete linings in sewerage shield tunnels were cracked causing water leakage, and 4) the Higashinada treatment plant suffered serious damage due to liquefaction, whereas the Port Island plant was sound due to soil improvement to increase the soil's resistance for liquefaction.

Key words: buried pipe, earthquake damage, liquefaction, sewage treatment plant, sewerage, shield tunnel (IGC: H5/H8)

INTRODUCTION

Table 1 shows an outline of the public sewerage systems for six cities in the Hanshin area of Japan (Osaka/Kobe). The 1995 Hyogoken-Nanbu earthquake impacted these sewerage systems causing damage to pipelines, treatment plants, and pumping stations. In this paper, the extent of this damage is outlined on the basis of the data obtained through the authors' investigations up to November 15th, 1995, and several cases having characteristic features compared to those in past earthquakes in Japan are presented.

Table 1. Sewerage systems for six cities in the Hanshin area

<table>
<thead>
<tr>
<th>City</th>
<th>Treatment area (ha)</th>
<th>Treatment system and pipeline length (km)</th>
<th>Number* of treatment plant</th>
<th>Pumping station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kobe</td>
<td>16029</td>
<td>Separate: Sanitary 3315, Storm 484</td>
<td>7</td>
<td>25</td>
</tr>
<tr>
<td>Osaka</td>
<td>18246</td>
<td>Combined: 4481</td>
<td>12</td>
<td>63</td>
</tr>
<tr>
<td>Nishinomiya</td>
<td>3240</td>
<td>Separate: Sanitary 451, Storm 106</td>
<td>5(2)</td>
<td>80(45)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combined: 320</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amagasaki</td>
<td>3980</td>
<td>Combined: 1018</td>
<td>4(1)</td>
<td>10(7)</td>
</tr>
<tr>
<td>Takarazuka</td>
<td>2663</td>
<td>Separate: Sanitary 321, Storm 118</td>
<td>0*</td>
<td>0</td>
</tr>
<tr>
<td>Ashiya</td>
<td>887</td>
<td>Separate: Sanitary 190, Storm 30</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combined: —</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note; *parenthesis: basin-wide systems; connected to 3 basin-wide systems

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Manuscript was received for review on August 7, 1995.
Written discussions on this paper should be submitted before August 1, 1996 to the Japanese Geotechnical Society, Sugayama Bldg. 4F, Kanda Awaji-cho 2-23, Chiyoda-ku, Tokyo 101, Japan. Upon request the closing date may be extended one month.
ing of the pipe structure along the longitudinal axis.
3) PVC (polyvinyl chloride) pipe: collapse of the pipe structure, cracking of the pipe structure along the circumference and the longitudinal axis, extrusion and displacement of the pipe at the joints, and intrusion of lateral sewers into the pipeline.
4) FRPM (fiber-reinforced plastic mortar) pipe: collapse and spirally cracking of the pipe structure.

Together with above, changes in grade and alignment of many pipelines were observed. In addition, large amounts of liquefied soils flowed into the pipelines. The length of dredging required to remove the liquefied soils from the pipelines was estimated to be 30 km in the southern coastal area of Amagasaki, 24 km in the northwest area of Osaka, and about the same order of lengths in reclaimed coastal areas of both Kobe and Nishinomiya. Inlets and lateral sewers were damaged to a great extent.

Many manholes were damaged and observed to consist of: horizontal displacement, cracking and collapse of assembled blocks, collapse of base concrete, intrusion of pipes into manholes, shear failure of pipes at the manhole walls, and horizontal displacement of steel manhole covers, examples of which are shown in Photo. 1. Extreme floatation of manholes due to liquefaction was seldom observed; in almost all cases, manholes projected above the ground surface due to the settlement of the adjacent ground.

The following characteristic features were observed in the damage of the pipelines produced by the 1995 Hyogoken-Nanbu earthquake, which were rarely reported in other past earthquakes in Japan:
1) Many trunk pipelines were damaged which caused flow of sewage to be disrupted.

<table>
<thead>
<tr>
<th>City</th>
<th>Extent of damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kobe</td>
<td>Emergency restoration of 24,544 locations in sanitary sewers: pipe collapse 284, manholes 1,516, lateral sewers 5,504, drainage appliance 15,135, closed 1,899, and others 206. Length of damaged sanitary sewers: branch sewers 48.5 km and trunk sewers 4.5 km. Emergency restoration of 417 locations in storm sewers: closed 50, damaged 354, and others 13.</td>
</tr>
<tr>
<td>Osaka</td>
<td>Length of damaged sewers: branch sewers (d=300 mm–500 mm) 1.7 km and lateral sewers 1.8 km. Collapsed inlets more than 400 locations. Collapsed manhole over 30 locations. Trunk sewers: no data.</td>
</tr>
</tbody>
</table>
| Nishinomiya   | Length of damaged branch sanitary sewers (sanitary and combined) 25.2 km: concrete pipe\(^1\) 14.7 km, PVC pipe\(^2\) 10.0 km, and FRPM pipe\(^3\) 0.5 km. Damaged trunk combined sewers\(^6\): 1.9 km of the total length \(L=49.9\) km (damaged ratio in terms of length \(R=3.8\)%). Storm sewers: no data.
  1) Internal diameter \(d=200\) mm–1950 mm, \(L=304.1\) km, and \(R=4.8\)%.
  2) \(d=200\) mm–600 mm, \(L=452.2\) km and \(R=2.2\)%.
  3) \(d=500\) mm–900 mm, \(L=1.5\) km and \(R=33.3\)%.
  4) Concrete pipes with \(d=1650\) mm–2400 mm.
| Amagasaki     | Length of damaged pipelines and their number of cracked locations: trunk lines\(^9\) 26.9 km and 265 points, branch lines\(^{10}\) 20.1 km and 728 points. Damage to manholes 280 locations. Damage to lateral sewers 982 locations.
  1) shield tunnels with \(d=4200\) mm–2000 mm (cracks of concrete lining), concrete pipes with \(d=3000\) mm–1650 mm and box culverts with 3800 mm × 3800 mm–2150 mm × 2700 mm. 2) \(d=250\) mm–800 mm. Length for replacement 9.4 km.
| Takarazuka    | Damaged sanitary sewers: pipes 2.9 km (mainly PVC pipe), manholes 166 locations, inlet 241 locations, and repaired manhole covers 147 locations. Damaged storm sewers: concrete pipes \((d=900\) mm) 102 m, concrete conduits \((U\) and \(L\) types) 4.2 km, and revetments (concrete block and lining wall) 2.1 km.
| Ashiya        | No data. |

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Table 2. Damage to pipeline systems

![Photo. 1. Damage to manholes: (a) displacement of block observed in Kobe, and (b) displacement of steel cover observed in Osaka](image-url)
Fig. 1. Locations of the damaged sewage treatment plants and pumping stations in five cities within the Hanshin area, including both damaged trunk pipelines and sewerage shield driven tunnels described in this paper.

Table 3. Damage to sewage treatment plants and pumping stations

<table>
<thead>
<tr>
<th>City</th>
<th>Extent of damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kobe</td>
<td>Higashinada plant: cf. Fig. 12. Chubu plant: collapse of concrete slab for aeration tanks, collapse of piping galleries, and cracking or differential settlement of secondary sedimentation basins. Seibu plant: collapse of inlet and outlet conduits, collapse of expansion joints in an aeration tank, and inclination of the hypochlorous acid tank. Sludge Center: machine troubles in plant. Pumping stations: 6 pumping stations stopped operating, mainly caused by submersion of equipped machines; cracking of 2 inlet conduits and an outlet conduit; breakage of 2 pressure pipelines, an aqueduct and 3 retaining walls.</td>
</tr>
<tr>
<td>Osaka</td>
<td>Cracking of outlet conduits, pressure pipelines and water leakage into pumping rooms etc. at 8 treatment plants and 7 pumping stations.</td>
</tr>
<tr>
<td>Nishinomiya</td>
<td>Naruohama plant: sag of an inlet conduit. Koshienhama plant: collapse of connection pipes in a chlorination tank. Edagawa plant: collapse of 2 sludge incinerators, and deposition of large amounts of fine soils in an initial sedimentation basin and inside an inlet conduit. Pumping stations: 12 pumping stations stopped operating due to breakage of inlet and outlet conduits etc.</td>
</tr>
<tr>
<td>Amagasaki</td>
<td>Tobu first plant: collapse of connection pipes between facilities etc. Tobu second plant: cracking in wall of sedimentation basin with inundation, and cracking of inlet and outlet conduits. Hokubu plant: shear breakage of a flexible joint for a connection pipeline with ( d = 800 \text{ mm} ). Pumping stations: 6 pumping stations were lightly damaged; opening of joints of an outlet conduit etc.</td>
</tr>
<tr>
<td>Ashiya</td>
<td>Ashiya plant and a pumping station: opening of joints of an outlet conduit and shear breakage of a pressure pipeline.</td>
</tr>
</tbody>
</table>
2) Cracks along the longitudinal axes of many concrete and PVC pipes were observed, regardless of differences in dimensions of the pipes and depths of the pipes below the ground surface.
3) Internal concrete linings of shield driven tunnels and concrete pipelines installed with jacking were cracked.
4) Almost all siphon pipelines crossing waterways collapsed.
5) Blocks, pipes and covers of manholes moved independently, resulting in displacement between them.
6) Flexible plastic pipes, made of PVC and FRPM, were damaged as much as concrete pipes.

Treatment Plants and Pumping Stations
19 treatment plants and 32 pumping stations, whose locations are shown in Fig. 1, were damaged and operations at most of these facilities were disrupted at these locations at least momentarily. Table 3 summarizes the extent of the damage. The common damage included: 1) inlet and outlet conduits (concrete boxes or pipes) and pressure pipelines were sheared downward causing breakage at the connection to structures, and 2) their joints were opened causing influx of the ground water or efflux of the sewage and the deposition of soils within them. The Higashinada treatment plant, in particular, in Kobe suffered serious damage, as is described later.

DISTRIBUTION OF DAMAGED PIPELINES IN NISHINOMIYA
Figure 2 shows in plan the distribution of the damaged branch pipelines in Nishinomiya, together with the position of faults and liquefied zones. Different sewage treatment systems (separate and combined) are adopted respectively in the north and south areas of Nishinomiya, which are divided by JR railroad line.

In the north area, PVC pipes having internal diameters of 100 mm–600 mm are mainly used as sanitary sewers. The structure of these pipes collapsed during the earthquake as shown in Photo. 2 (JGS, 1996) and all pipes were urgently replaced, while collapse of their joints was less. This feature of the damage suggests that the pipes were crushed by a strong seismic motion like a shock wave. The damaged pipelines in the north area were concentrated in a zone surrounded by two faults, the Koyo Fault and a lineament considered as an extension of the Itami Fault.

In the south area, concrete pipes with \(d=200\,\text{mm} - 1950\,\text{mm}\) (\(d\): internal diameter) were used mainly; both PVC pipes with \(d=200\,\text{mm} - 600\,\text{mm}\) and FRPM pipes with \(d=500\,\text{mm} - 900\,\text{mm}\) were used in a reclaimed island (Nishinomiya-hama). In most cases, damaged concrete pipes produced cracks along their longitudinal axes (cf. Photo. 3). There were several cases where rubber gaskets were removed from joints in the concrete pipes (cf. Photo. 4). In Nishinomiya-hama, FRPM pipes with \(d=500\,\text{mm} - 600\,\text{mm}\) collapsed at 5 locations and cracked spirally at 3 locations; the grade of a FRPM pipeline with \(d=900\,\text{mm}\) was changed for a length of 70 m. Many man-
holes were damaged in the manner as described in the former section. The locations of the damaged pipelines were just distributed in the liquefied zones.

A triangular-shaped area, therefore, where the damage in the pipelines was much less, remained in the center of Nishinomiya. In this area, there were several zones specified with seismic intensities of 6th-7th degrees. The seismic intensities in the south liquefied zone were below the 5th degrees. These examples indicate that the distribution of the pipe damage was basically independent of the seismic intensities that were determined on the basis of the damage in housing and building. A similar tendency was observed in other cities.

**DAMAGE IN LARGE CONCRETE PIPES**

Three concrete trunk pipelines in Nishinomiya and Kobe, whose locations are shown in Fig. 1, were seriously damaged.

In the Ohama trunk line 702.4 m long in Nishinomiya, 248 concrete pipes with lengths of 2.43 m and large diameters were installed using a jacking method, the depths of cover being from 2.7 m to 3.0 m. The internal diameters, wall thicknesses, and line lengths were 2,000 mm × 175 mm × 182.4 m, 2,200 mm × 190 mm × 290.6 m, and 2,400 mm × 205 mm × 229.4 m. Figure 3 shows the change in the line grade and locations of cracks. The pipelines floated in three zones; the maximum floating was recorded to be 80 cm. Moreover, 139 pipes among 248 were cracked along their longitudinal axes, whereas only 5 pipes were cracked along the circumference. The longitudinal cracks were located cross-sectionally at four points ±60° apart from the crown and ±45° from the invert, as shown in Photo. 5 (JGS, 1996). Almost all cracks were accompanied by water leakage from the outside. The structural system for the cracked pipes, therefore, became that of a four hinged arch, which is an unstable structural system. Figure 4 shows the soil profile at the Ohama pumping station, whose location is close to the
pipeline. The floating of the pipeline and observed deposition of liquefied soils on the ground surface suggest that the liquefaction of the upper sandy layer increased the damage to the pipeline.

In the Sanjo trunk line 248.1 m long in Nishinomiya, 2nd class concrete pipes of the socket type, whose dimensions are 1650 mm in internal diameter, 120 mm in wall thickness, and 2.36 m in length, were installed using an open excavation method on concrete beddings with 120° bedding angles (cf. Fig. 5), the depths of cover being 1.6 m-3.9 m. The bearing capacity of the pipes was specified as $Q=6.7$ KN/m (=6.8 tf/m), in which $Q$ is a pair of concentrated line loads applied on the top and bottom of the pipe at a standard two-edge loading test. Figure 6 shows the change in grade of the pipeline and location of pipes producing longitudinal cracks. The magnitude of the floating was not so great, however, while the cracks occurred in 70 pipes among the total of 106. Deposition of liquefied soils on the ground surface was observed in
this area after the earthquake. Figure 7 shows the soil profile at the Maehama pumping station, whose location is close to the pipeline, suggesting that liquefaction must have occurred in a loose sandy layer shallower than G.L.-8.5 m increasing the damage to the pipeline.

In the Fukiai-Nada trunk line in Kobe, 3rd class concrete pipes of the socket type with the same dimensions as those of the pipes used in the Sanjo trunk line were installed using an open excavation method on concrete beddings with 180° bedding angles (cf. Fig. 8), the depths of cover being 3.5 m-4.2 m. The bearing capacity of the pipes was specified as $Q=10.0 \text{ KN/m} (=10.2 \text{ tf/m})$. Cracks in the pipes occurred longitudinally for a length of 600 m. In particular, a length of 31.5 m of the pipeline suffered the most serious damage as shown in Photo. 6. Concrete revetments at the Takaba river just adjacent to the pipeline moved toward the river by 20-30 cm due to liquefaction, which increased the pipeline damage. This seriously damaged pipeline length (31.5 m) was urgently repaired by assembling steel liner plates inside the pipeline to achieve a 1300 mm internal diameter by grouting.
foam mortar into the annular space between the damaged pipeline and the liner plates.

In past earthquakes in Japan, the longitudinal cracks in large concrete pipes were not reported, except for only one pipe during the 1978 Miyagiken-oki earthquake (Tohoku Branch of JSCE, 1980). In general, the magnitude of flexural stiffness of the large concrete pipes along the circumference is calculated as $EI/12(1-\nu^2)$, which is considerably smaller than $E(I^4-d^4)/64(1-\nu^2)$ corresponding to the flexural stiffness in the longitudinal direction, in which $E$ and $\nu$ are Young’s modulus and Poisson’s ratio for concrete, $D$ and $d$ are the external and internal diameters of the pipe, and $t$ is the thickness of the pipe wall. It is natural, therefore, that large concrete pipes produced longitudinal cracks, when they were subjected to a strong shearing motion due to the transmission of the S-waves, although the effect of the liquefaction on the cracking has not yet been clarified.

**DAMAGE IN SEWERAGE SHIELD DRIVEN TUNNELS**

Many sewerage shield driven tunnels in Kobe, Amagasaki and Osaka produced cracks in their internal concrete linings that were placed on steel segments without reinforcing steel. The locations of damaged tunnels in Kobe are shown in Fig. 1; their total length was estimated to be around 10 km, which corresponds to 14% of the total length of the sewerage shield driven tunnels in Kobe. The damage in both the Naruo-Mikage trunk line and the Rokko Island connection line represent a typical example and a special one, respectively.

The Naruo-Mikage trunk line with a total length of 6 km was under construction with five shield tunnelings, #1–#5, to change the combined sewage treatment system at Higashinada Ward in Kobe to a separate treatment system (Hamaguchi et al., 1994). Table 4 shows the statistics for the five tunnelings. Figure 9 shows a plan and longitudinal alignment of Tunnel #1, together with the soil profile. The external linings for all tunnels, which were assembled with steel segments, were designed to support external loads. The internal concrete linings were designed not to support the external loads; their function was to provide smooth flow of the sewage and to prevent influx of the ground water and efflux of the sewage. All external and internal linings except for one internal lining of Tunnel #5 were completed before the earthquake.

The extent of the damage in Tunnels #1 and #2 was as follows:

1) **Tunnel #1**

The tunnel subsided for a length of 200 m near a vertical shaft located at the Higashinada treatment plant; the maximum settlement was recorded as 10 cm. Many circumferential cracks with widths of 3 mm–4 mm occurred in the vicinity of the shaft and at a sharply curved area with a radius of 60 m, as shown in Photo. 7. The spacing of the circumferential cracks along the longitudinal axis was either 1.8 m or 2.7 m corresponding to the multiples of the segment length of 0.9 m. This means that the circumferential cracks occurred at the locations of the segment joints, where the concrete linings were thinner by the beam heights of the segments. Circumferential cracks in the other area were considerably less than those in these areas. Longitudinal cracks, whose widths were around 0.3 mm, occurred for the entire length of the concrete lining. They were located in cross section at four points ±60° apart from the crown and ±30° apart from the invert. Concrete at the construction joints spalled for the entire tunnel length. Almost all circumferential and longitudinal cracks, together with the concrete spalling, accompanied the water leakage, as shown in Photo. 7.

2) **Tunnel #2**

Longitudinal cracks with widths of 0.2 mm–0.5 mm, occurred for the entire length of the concrete lining. Photograph 8 (JGS, 1996), which was taken 2 months after the earthquake, shows the state of these cracks; large amounts of lime fraction were leached out from the con-

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**Table 4. Statistics for five shield tunnelings in the Naruo-Mikage trunk line**

<table>
<thead>
<tr>
<th>Tunnel</th>
<th>Length (m)</th>
<th>Diameter*</th>
<th>Cover depth (m)</th>
<th>Stratum at the depth of tunneling**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$D$ (m)</td>
<td>$d$ (m)</td>
<td>Ground</td>
</tr>
<tr>
<td>#1</td>
<td>998</td>
<td>3.15</td>
<td>2.40</td>
<td>10–14</td>
</tr>
<tr>
<td>#2</td>
<td>1272</td>
<td>2.95</td>
<td>2.20</td>
<td>14–29</td>
</tr>
<tr>
<td>#3</td>
<td>1132</td>
<td>2.15</td>
<td>1.50</td>
<td>6–12</td>
</tr>
<tr>
<td>#4</td>
<td>960</td>
<td>2.15</td>
<td>1.50</td>
<td>6–8</td>
</tr>
<tr>
<td>#5</td>
<td>1774</td>
<td>2.75</td>
<td>2.00</td>
<td>8–18</td>
</tr>
</tbody>
</table>

Legend: *$D$: external diameter and $d$: internal diameter. **As: alluvial sand, Ds: diluvial sand, and Dg: diluvial gravel
crete lining to build small tubes like pillars. Circumferential cracks with widths of 0.3 mm–1 mm were scattered. Both longitudinal and circumferential cracks accompanied the water leakage.

Similar damage was also observed in Tunnels #3 and #4. There was, however, no damage and no water leakage in the external lining of Tunnel #5, where a concrete lining was not constructed. In Tunnels #1–#4, therefore, the existence of the concrete lining was likely to cause the water leakage from the joints of the steel segments, and the cracking in the internal concrete linings must have been caused by the difference in flexibility between the assembled steel segments and concrete linings. Although the function of the external linings in Tunnels #1–#4 to
support the loads may be sound, the water leakage in these tunnels must be stopped to avoid efflux of the sewage and a maintenance problem. This damage indicates the necessity for fundamental reconsideration of the method of the internal lining use in sewerage shield tunnels.

Figure 10 shows a plan and profile of the Rokko Island connection line (Kobe City, 1993). This shield driven tunnel was constructed for the installation of two pressure pipelines with $d=800$ mm and $500$ mm inside the tunnel to convey the sewage and cooling water between the Higashinada treatment plant and the Sludge Center (sludge incineration plant) on the Rokko Island. The length, external diameter, and internal diameter of the tunnel were 566.4 m, 2750 mm, and 2400 mm respectively. The tunnel was formed by assembling flat type RC segments 900 mm long and 175 mm thick without an internal concrete lining. As shown in Fig. 10, the tunnel was located in the upper portion of a diluvial sand layer ($D_s$). The depth of cover was 11.5 m–15.5 m under the seabed, 24.0 m at the mainland, and 31.5 m at the Rokko Island. Two vertical shafts were constructed using an open caisson method. Figure 11 shows the outline of the Rokko Island shaft, whose dimensions were $14 \times 11.0$ m $\times 42.04$ m with varying wall thicknesses of 1.2 m, 1.6 m and 2.0 m in accordance with an increase in depth. The mainland shaft had dimensions of $9.4 \times 9.4 \times 32.5$ m.

The extent of the damage in the tunnel and shafts was as follows:

1) RC segments placed in the crown part, except for the key segments, produced two or three longitudinal cracks for a length of 50 m at the Rokko Island, possibly due to

Photo 8. Longitudinal cracks in concrete lining of Tunnel #2 of the Naruo-Mikage trunk line in Kobe: (a) cracks and (b) tubes of lime fraction at cracks

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**Fig. 10. Plan and profile for the Rokko Island connection line**
the vertical ground motion during the earthquake. The cracks had openings of 0.2 mm-0.3 mm and extended over the entire length of the segments. They were located in cross section ±15 cm from the crown. Since the water leakage was not observed there, the damaged segments should still be able to support the external loads. There is, however, a possibility that similar cracks exist in the external parts of the segments placed at the springline of the tunnel, which may cause corrosion of the reinforcing steel in the segments in the future.

2) New water leakage from the segment joints was observed at four locations under the seabed area as shown in Photo. 9.

3) Flexible segments, which can deflect ±10 cm longitudinally, were placed in the vicinity to both vertical shafts. The flexible segments at the Rokko Island side were extended and those at the mainland side were compressed, both to almost the limitations, together with longitudinally bending.

4) Spalling of segmental concrete at the joints was observed at more than 10 locations.

5) The two vertical shafts were sheared horizontally causing cracking in the walls that accompanied the water leakage, as shown in Photo. 10. At the Rokko Island shaft, a 45° crack was located at a depth of 15 m; a construction joint, located at a depth of 18 m corresponding to the boundary between the fill layer and alluvial clay layer (A0) as shown in Fig. 11, was displaced horizontally by about 10 cm toward the sea side. The mainland shaft also produced both a 45° crack in the wall and a 5 cm horizontal displacement of a construction joint at a depth of around 14 m. This shaft inclined toward the sea side. The damage in both shafts was caused by lateral flow of the fill soils, which was produced by the lateral movements of the revetments due to liquefaction. The lateral movements of the revetments were observed to be approximately 2 m at the Rokko Island and 70 cm at the mainland side.

DAMAGE AT THE HIGASHINADA AND PORT ISLAND TREATMENT PLANTS

Figure 12 shows a plan view and damage at the Higashinada treatment plant. This plant was constructed in a reclaimed land area and was completed in 1962. The soil profile is shown from Borings #a–#c in Fig. 9. During the construction, improvement for a fill soil layer 12 m–15 m thick and a soft alluvial clay layer under it was not undertaken. The loose fill soil was therefore liquefied during the earthquake, resulting in lateral movement of revetments of a waterway dividing the plant by 1 m in the north-side and 2 m in the south-side. Settlement of the ground surface in the vicinity of the south-side revetment was around 1 m. The lateral movement and settlement of the ground caused serious damage to the plant facilities
Fig. 12. Plan and location of damage for the Higashinada sewage treatment plant

Collapse
1: Scrubbing building. 2: Settling basin. 3: Outlet pipe. 4: Cable connection bridge. 5: Crossing bridge for water supply. 6: Siphon conduits. 7: Gas tank. 8: Concentration tank. 9: Dewatering building. 10: Generation building. 11: Control building. 12: Sand filtration basin. 13: Inlet conduit for primary sedimentation basin. 14: Outlet conduit. 15: Connection pipelines between tanks.

Inclination and collapse of piles
A: Diversion tank. B: Sludge treatment tanks. C: Aeration tank and secondary sedimentation basin.

Collapse, Opening of joints, and submersion of pipe gallery: a–d.

Fig. 13. Subsoil improvement and soil profile before improvement at the Port Island sewage treatment plant
as shown in the figure. The plant stopped operating for a three month period after the earthquake, during which the sewage was temporarily treated in the waterway enclosed by sheet-piles. This serious damage to the Higashinada treatment plant indicates that different sewage treatment plants should provide pipelines interconnecting them with each other in order to cope with disruption resulting from an earthquake.

The Port Island treatment plant, completed in 1980, did not stop functioning, although an outlet conduit was damaged. As shown in Fig. 13, the subsoil conditions included a 20 m thick layer of fill soil (F1: a tuffaceous sand layer 12 m thick and F2: a decomposed granite layer 8 m thick), underlain by a 15 m thick layer of alluvial clay (Ac) and diluvial sand (Dc). Sand drains and rod compaction using H-piles were applied before the construction of the plant, as shown in the figure, to improve the Ac and F1 layers respectively. An increase in the liquefaction resistance of the fill soils due to this soil improvement technology resulted in considerably less damage in this plant than that in the Higashinada treatment plant. This is a good example of how to minimize damage due to liquefaction for sewage treatment plants, which are usually constructed on soft subsoils in coastal areas.

CONCLUSIONS

Damage in the sewerage systems due to the 1995 Hyogoken-Nanbu earthquake was outlined. Their characteristic features compared to those in past earthquakes in Japan were detailed, as follows:

1. The damaged sewerage pipelines in Nishinomiya were concentrated in liquefied zones and in an area surrounded by two faults. The intensities of the pipeline damage did not correspond to the seismic intensities that were determined from the damage in housing and buildings.

2. Three large concrete pipelines with a total length of 1550.5 m were heavily cracked longitudinally causing them to be unstable. This type of longitudinal cracks was seldom reported in past earthquakes.

3. In Kobe, internal concrete linings of shield driven sewerage tunnels were cracked resulting in water leakage, the total length of which was estimated to be around 10 km. Similar crackings were observed in Amagasaki and Osaka.

4. The Higashinada sewage treatment plant suffered serious damage due to liquefaction which caused it to stop functioning for a period of three months, whereas the Port Island treatment plant did not stop functioning due to soil improvement having been used for the plant construction.

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