Sewer Pipe Maintenance

Kitakyushu City Water and Sewer Bureau
August 2015
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Background

• February 1963: Five cities merge into Kitakyushu City and full-scale development begins; 50 years have passed
• July 1963: Kogasaki Sewage Treatment Plant begins operating
• March 2006: Sewer system diffusion rate reaches 99.8%

Main Sewer Facilities

• Five treatment plants
  (Treatment capacity: 621,000 m²/day)
• Pump stations: 34
• Pipe: 4,447 km
Kitakyushu City Sewer Pipe Coverage

◆ Total length: 4,447 km
  - Sewer pipe: 3,245 km (73%)
  - Drainage pipe: 345 km (8%)
  - Combined sewer pipe: 857 km (19%)

![Graph showing the length of sewer pipes by installation year]
Kitakyushu Airport sewage is treated at Sone Sewage Treatment Plant.

About 24 km from Yobuno, Kokuraminami-ku to Hiagari Sewage Treatment Plant.
Sewer Pipe Diameter

◆ Diameter

<Minimum>
- Sewer pipe: 150 mm
- Drainage pipe: 500 mm
- Combined sewer pipe: 250 mm

<Maximum>
- 5,000 mm (combined sewer pipe)

[Length by diameter]

- Diameter 800 mm or greater
  - L = 639 km
  - 15%

- Diameter less than 800 mm
  - L = 3,755 km
  - 85%
Pipe Material

◆ Pipe type

- PVC pipe is the main material of small (diameter 150-300 mm) pipes
  - Installation is easy;
    it is lightweight and can be installed in standard sections of 5 m
- Clay pipes were standard during initial construction (200-400 mm)
  - Excellent acid- and alkali-resistance
    → Concern over cracks and damage because they are not very shock resistant
- Ductile cast iron piping (DCIP) is used for pumping

[Length by pipe type]

- Chloride vinyl
- Ceramic
- Hume
- Ductile cast-iron
- Concrete
- Others

- Chloride Vinyl
  L=1,070km
  24%
- Ceramic
  L=2,024km
  46%
- Ductile cast-iron
  L=142km
  8%
- Concrete
  L=330km
  8%
- Hume
  L=709km
  16%
- Others
  L=119km
  3%
- Others
  L=119km
  3%
Pipe Length by Year of Installation

- Concentrated investment in pipe construction (1972-1986) to improve diffusion rate: Around 2,200 km

*Pipe maintenance will become even more important with the increase in pipes approaching their service lives of 50 years.*
Trends in Calls for Emergency Maintenance

* Obstructions tend to increase along with age and deterioration

→ Kitakyushu City has established a 24-hour emergency service system to respond to insufficiencies.
Examples of Obstructions in Kitakyushu City

-Damaged pipes-

Road subsidence

Sewer flooding, foul odors
Once sewer pipes go into service, they must remain in service for many years. Proper maintenance is crucial.

If pipes are not maintained sufficiently, they can:

- Interfere with city residents’ lives
  - road subsidence, groundwater pollution, slow drainage, foul odors, flooding
- Interfere with business
  - delaying or slowing planning, designing, construction, etc.
## Asset and Functional Management

(1) **Asset management:** What kinds of assets exist?

(2) **Functionality management:** Is each asset consistently put into operation?

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-category</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Asset Management</td>
<td>Property management</td>
<td>Controlling acquisition periods and prices, ensuring safety</td>
</tr>
<tr>
<td></td>
<td>Facilities, equipment and machinery</td>
<td>Managing construction dates, purchase prices, residual value, etc.</td>
</tr>
<tr>
<td>(2) Functional Management</td>
<td>1) Surveys and inspections</td>
<td>Fully understand the current state of the pipes (presence or lack of damage, deterioration, etc.)</td>
</tr>
<tr>
<td></td>
<td>2) Cleaning and dredging</td>
<td>Ensure flow capacity, prevent pipe deterioration</td>
</tr>
<tr>
<td></td>
<td>3) Repairs and reconstruction (upgrades)</td>
<td>Preserve facilities</td>
</tr>
</tbody>
</table>
Pipe Maintenance Methods: (1) Asset Management

◆ Asset management is the foundation of management

* Acquired assets should be fully and properly understood
  • Property: Controlling acquisition periods and prices, ensuring safety
  • Facilities, equipment and machinery:
    Managing construction dates, purchase prices, residual value, etc.

* Practice management in Kitakyushu City through ledgers
  → The law requires that these records are prepared, stored and publicized.

<Examples of entries into sewer system ledgers>
  • On-site reconstruction work in response to obstructions
  • Planning and consideration for planning, etc.
  → These documents form the foundation of pipe maintenance operations

* It is crucial for as-built drawings to accurately reflect each building.
Sewer system ledgers:
For general purposes (viewable by city residents)

<Ledger data>
- Types of pipe
  (sewer, drainage, Combined sewer)
- Pipe diameters
- Slopes
- Lengths
- Construction dates
- Pipe bottom elevations
- Ground elevations
- Manhole types
- Inlet locations
Kitakyushu City Maintenance System

- Maintenance system: Mainly used during maintenance and design stage

- A system based on sewer system ledgers and including records of past surveys, map information and the like used for a wide array of maintenance operations
Combines information about pipe surveys for integrated management of pipe status.
* Combine various information and illustrate

Understand the relationship between pipes, geological information about their locations, types of roads, etc.
Reference: A Similar System

- GIS: Mainly used when drafting plans

<Developed by a business in Kitakyushu City>

Uses “Geographic Information System” (GIS) technology to search, extract, display and illustrate various information

http://www.geo-craft.co.jp

(Example) Extraction of deteriorating pipes

(Example) Tracking water supply and sewer pipes

Image of GIS
Pipe Maintenance Methods: (2) Functional Management

Functional management is for ensuring consistent sewer system operation

1) Surveys and inspections: Fully understand the current state of the pipes (present damage, deterioration, etc.)

2) Cleaning and dredging: Ensure flow capacity, prevent pipe deterioration

3) Reconstruction and repairs: Preserve facilities

*Ensure the continuous functioning of the sewer system

Functionality management flow

1. Surveys and inspections
   - Patrons and inspections: Everyday, above-ground visual inspections of street and manhole conditions

2. Manhole interior survey
   - Enter manholes to visually survey the characteristics inside manholes and pipes

3. Pipe interior survey
   - Use a video camera or dive underwater to survey the characteristics inside pipes

Trouble detected

Cleaning and dredging
- Clear away sediment, obstructions and the like by hand or with a mobile pressure washer.

Reconstruction and repairs
- Repair or rebuild the troubled area
### Types and Frequencies of Inspections and Surveys

#### Frequency of Inspections and Surveys

<table>
<thead>
<tr>
<th>Item</th>
<th>Location</th>
<th>Years in service</th>
<th>Survey frequency</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patrols and inspections</td>
<td>Above ground</td>
<td>0-30 years</td>
<td>Once every three years</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 years or more</td>
<td>Once every year</td>
<td></td>
</tr>
<tr>
<td>Visual manhole interior survey</td>
<td>Manhole interiors and water and sewer pipes</td>
<td>0-30 years</td>
<td>Once every five years</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 years or more</td>
<td>Once every three years</td>
<td></td>
</tr>
<tr>
<td>Visual underwater survey</td>
<td>Inner radius at least 800 mm</td>
<td>0-30 years</td>
<td>Once every 10 years</td>
<td>Includes collecting sewers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 years or more</td>
<td>Once every seven years</td>
<td>Includes collecting sewers</td>
</tr>
<tr>
<td>Video camera survey</td>
<td>Inner radius less than 800 mm</td>
<td>0-30 years</td>
<td>Once every 10 years</td>
<td>Includes collecting sewers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 years or more</td>
<td>Once every seven years</td>
<td>Includes collecting sewers</td>
</tr>
</tbody>
</table>

* It is best to increase survey frequency after pipes have been in service for 30 years to combat progressive damage and deterioration (further care is required for facilities in use past the standard 50-year service life)

With over 4,400 km of pipe in Kitakyushu City, it is difficult to secure a budget for conducting inspections and surveys at these frequencies. Use inspection records and the like to evaluate deterioration and create inspection plans, then systematically carry out inspections and surveys.
1. Surveys and inspections

◆ Survey Methodology

- Small pipes (diameter less than 800 mm): Use a video camera
- Large pipes (diameter 800 mm or larger): Visual survey
◆ Pipes to be surveyed (as of 2011)

• Large diameter, 20 or more years of service: $L = 435/639$ km (68%)
• Small diameter, 30 or more years of service: $L = 1,793/3,755$ km (48%)

<State of implementation>
(Large) $L = 399$ km (92%)  (Small) $L = 1,372$ km (77%)

* Systematic surveys are required because the number of deteriorated pipes will increase significantly in the near future

→ Securing a budget for surveys is a major challenge
<table>
<thead>
<tr>
<th>Evaluation across entire spans</th>
<th>Deterioration level</th>
<th>Corrosion of pipes, rebar showing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow capacity</td>
<td>Sagging above or below</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Evaluation for individual pipes</th>
<th>Deterioration level</th>
<th>Damage to pipes, cross-sectional deformation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaks</td>
<td>Cracks in pipes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Misalignment or gaps in pipe joints</td>
<td></td>
</tr>
<tr>
<td>Flow capacity</td>
<td>Gushing or seepage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Protrusion of collecting sewers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Greasy buildup</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Invasion of tree roots</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clumps of mortar</td>
<td></td>
</tr>
</tbody>
</table>
Examples of Obstructions in Pipes

<Obstructions detected through video camera surveys>

### Accumulation of mortar
- **Cause:** Illegal dumping into the sewer system
- **Remedies:**
  - Cleaning with a mobile pressure washer
  - Removal with a drilling robot
- **Cost:**
  - 170,000 yen/span for mud pump truck and mobile pressure washer
  - 70,000 yen/location for drilling robot

### Corrosion and blockage
- **Cause:** Corrosion by hydrogen sulfide, etc.
- **Remedy:** Pipe replacement

### Invasion of tree roots
- **Cause:** Invasion from trees on streets and in parks
- **Remedy:** Root cutting with a mobile pressure washer
- **Cost:** 90,000 yen/span for mobile pressure washer
- *Partial repairs and rehabilitation work may be required to prevent roots from invading the pipes again*
Examples of Obstructions in Pipes

<Obstructions detected through video camera surveys>

<table>
<thead>
<tr>
<th>Misalignment</th>
<th>Groundwater leakage</th>
<th>Poor connection of collecting sewers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cause: Faulty construction, subsidence due to passage of time</td>
<td>Cause: Faulty construction, subsidence due to passage of time</td>
<td>Cause: Faulty construction</td>
</tr>
<tr>
<td>Remedies: Partial repairs (minor misalignment)</td>
<td>Remedy: Partial repair</td>
<td>Remedy: Removal with a drilling robot</td>
</tr>
<tr>
<td>Excavate and replace (major misalignment)</td>
<td>Cost: 140,000 yen/location for partial repair</td>
<td>Cost: 70,000 yen/location for drilling robot</td>
</tr>
<tr>
<td>Cost: 140,000 yen/location for partial repair</td>
<td>* Perform rehabilitation work in places with many leaks</td>
<td>* Perform rehabilitation work in places with many leaks</td>
</tr>
</tbody>
</table>
Kitakyushu City Criteria

◆ Use survey results to assign point values to damage level, and determine the proper remedy

• Urgency Level → Determine the timing of the remedy
• Remedy → Partial repair or reconstruction of entire spans

<Relationship between damage level and urgency level>

**Damage level (points/meter)**

= total damage points for the span/span length

<table>
<thead>
<tr>
<th>Damage level</th>
<th>Urgency level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 points or more</td>
<td>A: Urgent need for reconstruction or repairs</td>
</tr>
<tr>
<td>1.0 points or more, less than 1.5 points</td>
<td>B: Pressing need for reconstruction or repairs</td>
</tr>
<tr>
<td>Less than 1.0 points</td>
<td>C: Check progress during the next survey</td>
</tr>
</tbody>
</table>
# Damage Ranking Chart

<table>
<thead>
<tr>
<th>Damage Type</th>
<th>Name</th>
<th>Level</th>
<th>Points</th>
<th>Damage Type</th>
<th>Name</th>
<th>Level</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe damage</td>
<td>Missing, collapse</td>
<td>A</td>
<td>10</td>
<td>Cracks</td>
<td>Spider web pattern</td>
<td>A</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Deformity</td>
<td>B</td>
<td>8</td>
<td></td>
<td>Many</td>
<td>B</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Visual hole</td>
<td>C</td>
<td>6</td>
<td></td>
<td>Some</td>
<td>C</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Exposed rebar</td>
<td>A</td>
<td>6</td>
<td>Leaks</td>
<td>Gushing</td>
<td>A</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Exposed aggregate</td>
<td>B</td>
<td>4</td>
<td></td>
<td>Dripping</td>
<td>B</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Rough surface</td>
<td>C</td>
<td>2</td>
<td></td>
<td>Seeping</td>
<td>C</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1/4 pipe diameter or greater</td>
<td>A</td>
<td>4</td>
<td>Invasion by tree roots</td>
<td>1/4 pipe diameter or greater</td>
<td>A</td>
<td>6</td>
</tr>
<tr>
<td>Pipe wear</td>
<td>Exposed rebar</td>
<td>A</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Exposed aggregate</td>
<td>B</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rough surface</td>
<td>C</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Past exposed rebar</td>
<td>A</td>
<td>10</td>
<td>Sagging</td>
<td>1/2 pipe diameter or greater</td>
<td>A</td>
<td>4</td>
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<tr>
<td></td>
<td>Surface corrosion</td>
<td>B</td>
<td>7</td>
<td></td>
<td>1/4 pipe diameter or greater</td>
<td>B</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Partial corrosion</td>
<td>C</td>
<td>6</td>
<td></td>
<td>Less than 1/4 pipe diameter</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1/3 pipe diameter or greater</td>
<td>A</td>
<td>3</td>
<td>Collecting sewer protrusion</td>
<td>1/3 pipe diameter or greater</td>
<td>A</td>
<td>0</td>
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<td></td>
<td>Less than 1/3 pipe diameter</td>
<td>B</td>
<td>1</td>
<td></td>
<td>1/5 pipe diameter or greater</td>
<td>B</td>
<td>0</td>
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<tr>
<td></td>
<td>1/5 pipe diameter or greater</td>
<td>A</td>
<td>0</td>
<td></td>
<td>Less than 1/5 pipe diameter</td>
<td>C</td>
<td>0</td>
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<tr>
<td></td>
<td>1/10 pipe diameter or greater</td>
<td>B</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Less than 1/10 pipe diameter</td>
<td>C</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Points are not assigned for mortar accumulation or collecting sewer protrusion. This is because it is believed that removing those problems can restore pipe functionality.
Urgency Level Determination Method 1

<Pipe network map (GIS format)>

<Pipe survey data>

<Summary table>

<table>
<thead>
<tr>
<th>Item</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe damage</td>
<td>E</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Cracks</td>
<td>H</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>Pipe wear</td>
<td>W</td>
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</tr>
<tr>
<td>Leaks</td>
<td>D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joint misalignment</td>
<td>G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree roots</td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipe corrosion</td>
<td>F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sagging</td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meandering</td>
<td>M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protrusion of collecting sewers</td>
<td>K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mortar and concrete</td>
<td>Q</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>6</td>
<td>10</td>
</tr>
</tbody>
</table>
<Summary table>

<table>
<thead>
<tr>
<th>Item</th>
<th>—</th>
<th>A</th>
<th>B</th>
<th>C</th>
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</thead>
<tbody>
<tr>
<td>Pipe damage</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaks</td>
<td>D</td>
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<td></td>
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<tr>
<td>Joint misalignment</td>
<td>G</td>
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<tr>
<td>Mortar and concrete</td>
<td>Q</td>
<td>0</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>—</td>
<td>0</td>
<td>6</td>
<td>10</td>
</tr>
</tbody>
</table>

**Determination Method**

Span length $L = 18.9$ m

Pipe damage $C$ 1 location x 6 points = 6 points
Cracks $B$ 6 locations x 4 points = 24 points
Pipe wear $C$ 9 locations x 2 points = 18 points
Total = 48 points

Damage level (points/meter)

= total damage points for the span/span length

= 48 points/18.9 m = 2.53 points

As it is over 1.5 points, the urgency level is **A**

<table>
<thead>
<tr>
<th>Damage level</th>
<th>Urgency level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 points or more</td>
<td>A: Urgent need for reconstruction or repairs</td>
</tr>
<tr>
<td>1.0 points or more, less</td>
<td>B: Pressing need for reconstruction or repairs</td>
</tr>
<tr>
<td>than 1.5 points</td>
<td></td>
</tr>
<tr>
<td>Less than 1.0 points</td>
<td>C: Check progress during the next survey</td>
</tr>
</tbody>
</table>
Suppose a damaged area of one meter per location with damage, and compare to span length to determine the reconstruction or repair method.

- If 1/3 or greater of span length = reconstruct
- If less than 1/3 of span length = repair

Example: Cracks, leaks and other damage in five locations

Span length $L = 10.0 \text{ m}$

Reconstruct in this case ($5 \text{ m} \geq 10 \text{ m} \times \frac{1}{3}$)
2. Cleaning and dredging

◆ Cleaning and dredging methods

- Small pipes (diameter less than 800 mm): Use a mobile pressure washer
- Large pipes (diameter 800 mm or greater): Workers enter pipes and aspirate with a mud pump truck

Ensuring safety during dredging work

Prevent hydrogen sulfide poisoning and oxygen deficiency by taking measurements before and during work

Prevent obstruction of traffic by service vehicles, machinery and equipment by receiving permission from police departments in advance, installing barricades, etc.
<Implementation policy>

- Respond promptly to locations that have been complained about
- Perform preventive maintenance
  - Clean/dredge siphon sections each year (around 70 locations)
  - Twice each year, clean/dredge junction pipes where the odor has been complained about
  - Regularly clean manhole pumps, air valves and other components in addition to pipes
(3) Reconstruction and repairs

• Definition of reconstruction and repairs
  – Reconstruction: Rebuilding or replacing all or parts of certain facilities
  – Repairs: Replacing parts of certain facilities

• Reconstruction and repairs of pipes
  – Reconstruction: Rehabilitating or rebuilding one span
  – Repairs: Partial repairs
Types of Reconstruction and Repairs

- **Reconstruction**
  - Rehabilitation methods
    - Single-structure pipe
    - Integrated pipe
    - Double-structure pipe
  - Pipe replacement method
    - Excavation method
    - Reconstruction promotion method

**Integrated pipe**
- Flat ring or other type of material for joints
- Rehabilitation material
- Filler

**Single-structure pipe**
- Rehabilitation material (resin, ____ , film, etc.)

- Existing pipe
- Integrated Pipe Diagram
- Single-Structure Pipe Diagram
What are rehabilitation methods?

Building a new pipe (rehabilitated pipe) inside an existing pipe without excavating.

Characteristics of rehabilitation methods

- Lower construction cost
- Shorter construction schedule
- Less construction impact
- Work is difficult to perform on horribly damaged pipes.
- Smaller cross-sections
  → Handle by improving roughness coefficient
### Rehabilitation Methods Used in Kitakyushu City

<table>
<thead>
<tr>
<th>Type of work</th>
<th>Work method</th>
<th>Type of structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cured-in-place pipe inversion method</td>
<td>SGICP</td>
<td>Hose lining</td>
</tr>
<tr>
<td></td>
<td>Insituform</td>
<td>Epofit</td>
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<tr>
<td></td>
<td>C-ONE</td>
<td>Through ring</td>
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<tr>
<td></td>
<td>Two-way lining</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Double-structure pipe (Structure expected to have the strength of the existing pipe) or Single-structure pipe (Structure not expected to have the strength of the existing pipe)</td>
</tr>
<tr>
<td>Fold-and-form method</td>
<td>EX</td>
<td>FFT-S</td>
</tr>
<tr>
<td></td>
<td>All Liner</td>
<td>Omega Liner</td>
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<tr>
<td></td>
<td>Paltem SZ</td>
<td>Seamless system</td>
</tr>
<tr>
<td></td>
<td>Polyethylene compact pipe</td>
<td></td>
</tr>
<tr>
<td>Pipe lining method</td>
<td>SPR</td>
<td>Paltem Flooring</td>
</tr>
<tr>
<td></td>
<td>Danby</td>
<td>3S segment</td>
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<tr>
<td></td>
<td>PFL</td>
<td></td>
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<tr>
<td>Pipe lining method</td>
<td>Casing method</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Integrated pipe (integrating existing pipe with rehabilitation material)</td>
</tr>
</tbody>
</table>
Cured-in-place pipe inversion method

Lining material is inverted and inserted by applying hydraulic or air pressure through an access hole, and then hardened with hot water, steam or light.

- **Characteristics**
  - Used on small pipes (diameter less than 800 mm) in Kitakyushu City
  - Can form new pipes connected seamlessly
  - Cannot work with pipe in service (water must be cleared away)
Lining material is pulled in through an access hole, expanded to pressure bond by hydraulic or air pressure and hardened with hot water, steam or light.

- **Characteristics**
  - Used on small pipes (diameter less than 800 mm) in Kitakyushu City
  - Can form new pipes connected seamlessly
  - Cannot work with pipe in service (water must be cleared away)

Fold-and-Form Method Diagram
Existing pipes are lined by fitting PVC or other material inside, and gaps with the existing pipe are reinforced with mortar, etc.

- **Characteristics**
  - Used on large pipes (diameter 800 mm or greater) in Kitakyushu City
  - Can be used on rectangular cross-sections
  - Can work with pipe in service (but not for some methods)
  - Can work even with slight unevenness or bends in existing pipes

---

**Pipe Lining Method Diagram**

- Lining belt coiler
- Manhole
- Flat ring or other type of material for joints (lining belt)
- Lining machine
- Existing pipe

---
Secondary product pipe material of a diameter smaller than existing pipe is pulled into the pipe, and gaps with the existing pipe are reinforced with mortar, etc.

**Characteristics**
- Used on large pipes (diameter 800 mm or greater) in Kitakyushu City
- Can work with pipe in service
- Inclined walls, straight walls and slabs must be removed for work
- There are limitations due to curvature radius or work on uneven sections
Kitakyushu City Reconstruction Plans

◆ Basic Approach

Reconstruction will continue as required as a more precise understanding of pipe conditions is gained.

- Large pipes: Extremely important, implement promptly
- Small pipes: Implement systematically with attention paid to administrative aspects


Pipes requiring reconstruction:

- Large pipes: 4.8%, 17/352 km (20 or more years since installation)
- Small pipes: 14.2%, 49/348 km (30 or more years since installation)

<Implementation target level>

Reconstruct around 25 km of pipe per year (1.5 km large, 23.5 km small)

⇒ Realistically, this is difficult …
• Kitakyushu City established estimate and productivity targets for designing rehabilitation methods in 1998 (before then, work was done experimentally)

• Since then rehabilitation methods have been used to carry out most reconstruction work.
Rehabilitation Method Report

Rehabilitation Length (km) vs Fiscal Year

- **Inversion method**
- **Forming method**
- **Winding method**

**Legend**
- Light blue: L=79km (38%)
- Yellow: L=18km (9%)
- Dark red: L=109km (52%)

**Fiscal Year**
Comparison of Rehabilitation Methods

Pipe lining method

- PALTEM 17%
- Danby 24%
- SPR 54%
- PFL 4%
- 3S segment 1%

<Cured-in-place pipe inversion method>

- Through Ring 2%
- Insituform 7%
- ALL LINER 1%
- SGICP 38%
- INPIPE 17%
- Hose-Lining 35%

<Cured-in-place pipe inversion method>

- Omega Liner 4%
- FFT-S 8%
- EX 19%
- Seamless system 36%
- PALTEM SZ 4%
- ALL LINER 29%
Impact of Hydrogen Sulfide

- Harmful: Leads to accidents during work
- Corrosive: Weakens sewer system functionality
- Foul-smelling: Leads to complaints

Road subsidence
**Hydrogen Sulfide Concentrations and Human Reactions**

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂S 0.025-10 ppm</td>
<td>Rotten egg smell</td>
</tr>
<tr>
<td>H₂S 10-50 ppm</td>
<td>Acclimation to the odor leads to unawareness of stronger concentrations</td>
</tr>
<tr>
<td>H₂S 50-300 ppm</td>
<td>Feels like sand in the eyes, pain increases</td>
</tr>
<tr>
<td>H₂S 300-600 ppm</td>
<td>Intense, burning pain in the respiratory tract mucosa, threat to life</td>
</tr>
<tr>
<td>H₂S 600 ppm or higher</td>
<td>Respiratory arrest, death</td>
</tr>
</tbody>
</table>
Hydrogen Sulfide Corrosion
**Natural outflow through uneven manhole**

- **Downstream side**
  - If there is a receiving well with pressure pipe upstream
    - \( y = \alpha(25x + 100) \)
  - If there is no receiving well with pressure pipe upstream
    - \( y = \alpha(25x) \)

- **Upstream side 1 span**

**Receiving well with pressure pipe downstream**

- \( y = \alpha(220x - 50) \) \((x \geq 0.75)\)
- \( y = \alpha(25x + 100) \) \((0 < x < 0.75)\)

\( y \) = corrosion range  
\( x \) = length of uneven section  
\( \alpha \) = safety factor (1.0)
Hydrogen Sulfide Treatments

• Stabilize oxidization of sulfides
  • Chemical injection
    • Chemicals are expensive, thus this is an effective emergency measure

• Prevent turning anaerobic
  • Air injection
    • Economically effective, but attention must be paid to downstream obstructions
  • Oxygen injection
    • Substantial effects, but high construction cost
Example of Hydrogen Sulfide Treatment in Kitakyushu City (Air Injection)

- **Air injection** = 0.5 m³/minute (2 x 500-mm diameter)
- **Air injection** = 1.0 m³/minute (2 x 500-mm diameter)

**Hydrogen sulfide concentration (ppm)**

- **No air injection**

<table>
<thead>
<tr>
<th>October</th>
<th>November</th>
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<tr>
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</tbody>
</table>

Graph showing daily hydrogen sulfide concentration trends from October 6 to November 9.
(1) 24-hour emergency response system

Objective: To establish a 24-hour emergency service system to respond to insufficiencies.

Overview: Establish a system in which workers who repair, clean and dredge enter contracts with each city ward and can provide 24-hour service throughout the year.

(2) Secondary Pressure Pipes

Install second sets of pressure pipes to enable water delivery by a different route if original pipes are damaged and service is cut off (prompt emergency response or replacement are possible).
Actual example

Damage occurred to pipes along the red route

Emergency workers conducted a survey and reported results

Water service only on the blue route began soon after the accident

Emergency workers began reconstruction work (completed reconstruction the following day)

Because the emergency workers were ready and the secondary pipes were installed, the problem was solved without cutting off sewer service.