4-2-3  Seismic Retrofitting Measures for Sewerage Structures in Tokyo

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Key Words
Earthquake, Earthquake resistance measures, Trenchless technology, Liquefaction, Construction works

Abstract
The capital city Tokyo is the center of Japan's politics and economy, and urban infrastructure such as roads and water supply and sewerage support vigorous urban activities. For this reason, it is of utmost importance to take countermeasures against earthquakes for urban infrastructure. The Bureau of Sewerage, Tokyo Metropolitan Government (TMG) has been working on earthquake resistance measures such as making manholes and pipe connections earthquake resistant and prevention of manhole floating. This paper introduces earthquake resistance measures for sewer pipes in Nagatacho and Kasumigaseki District (NKD) where the capital's core functions are concentrated. Although there were many restrictions regarding construction time etc. due to necessity for coordination with many government offices and competing constructions, we could complete the work by making use of the features of seismic reinforcement technology by trenchless technology to make work procedure and working time efficient and minimize the impact on road traffic and the surrounding environment.

1. Introduction

Japan was hit by major earthquakes until now often, and the sewerage facilities were damaged due to those earthquakes. In the Great Hanshin-Awaji Earthquake occurred in January 1995, damage, protrusion, misalignment and cracking of the sewage pipes occurred, and damages were frequently observed at the connection between the sewer pipes and manholes. These damages were caused by rigid joint structure between manholes and sewer pipes which cannot absorb the
difference of movement between manholes and sewer pipes induced by earthquake motion (Picture 1). In the Niigata-ken Chuetsu earthquake in 2004, liquefaction phenomena occurred due to strong tremors, and it caused many cases of manhole floating. Manhole floating not only impairs the function of the sewers but also hindered road traffic by salient manholes above the ground and affected emergency restoration activities and relief and rescue activities at the time of earthquakes (Picture 2).

In the Great East Japan Earthquake that occurred in 2011, the administrative buildings in the coastal area of Tohoku District were damaged, administrative functions and economic activity stagnated. In the Kanto Region, liquefaction phenomena occurred and damage was extensive. Tokyo is said that within the next 30 years there will be a 70% chance of an epicentral earthquake directly under the capital occurring, and if Tokyo were to be damaged similarly, the whole country would be affected enormously. In particular, in NKD, core functions of the Japanese capital such as the National Diet are concentrated, and the importance of countermeasures against earthquakes for sewer pipes is extremely high.

2. The Importance of Earthquake Resistance Measures in Tokyo

2.1. Seismic Reinforcement Technology Supporting Countermeasures against Earthquake

The Bureau of Sewerage, TMG supported the development of seismic reinforcement technology of private enterprises in response to the damage of sewer pipes caused by earthquakes and put them into practical use. We jointly developed a technology to make the junction of a sewer pipe and a manhole with flexible structure (trenchless technology of seismic reinforcement construction: TTSRC) and a technology to prevent liquefaction phenomena around manholes (trenchless technology of manhole floating prevention: TTMFP) with private enterprises and have been promoting earthquake resistance of sewer pipes.

TTSRC responds to bending and protrusion at the time of earthquake by cutting the outer parts of the pipe (manhole side wall part) with a cutting machine from inside the manhole and injecting elastic joint material into the cut part. By doing this, it is possible to secure the flowing function of the sewer (Figure 1, Picture 3).

TTMFP refers a method that a wall is drilled from the interior of a manhole (Picture 4), a pressure relief valve (dissipation valve: Picture 5) is attached, and the excess pore water pressure is dissipated into the manhole through the dissipation valve (Figure 2).
By suppressing the impact on the manhole caused by liquefaction, it is possible to prevent manhole floating and to reduce the influence on the road traffic.

Since these two construction methods apply seismic reinforcement from the inside of the existing manhole, construction can be done without road excavation by keeping sewage flowing, and the cost is lower and the construction time is shorter than the construction method to replace the manhole. In addition, since the equipment used is small and easy to move, the noise and vibration accompanying the work is also small. Furthermore, as only few ground facilities are required and the work can be done inside the manhole, using these methods can also suppress the impact on road traffic and pedestrians.

2.2. Countermeasures against Earthquakes for Sewer Pipes in Tokyo Metropolis

The total length of sewer pipes managed by the Bureau of Sewerage, TMG is approximately 16,000 km and the number of manholes reaches 480 thousand, and thus, it takes a lot of time and expense to apply seismic reinforcement to all of these sewer pipes. For this reason, TMG gave priority to districts where people gather at the time of earthquake and has been taking countermeasures against earthquake for these prioritized areas and facilities. TTSRC has been applied to sewer pipes receiving sewage from evacuation centers where people gather at the time of earthquake, disaster recovery bases designated by the state, the Metropolitan Government or each ward, terminal stations, areas where evacuation is not necessary where people can stay within the districts as there is no fear of large-scale fire and evacuation is not required, etc. In particular, since the damage of the sewage was concentrated on the sewer pipes with the diameter of 800 mm or less, we have been working on the pipes with diameter of 800 mm or less.
In addition, TTMFP has been applied to emergency transportation roads that support material transportation and emergency restoration at the time of earthquake and access roads connecting the emergency transportation roads to each evacuation center and disaster recovery base within the areas where liquefaction is predicted (Figure 3).

3. Problem definition

3.1. Overview of Nagatacho and Kasumigaseki District (NKD)

NKD, located in the southwest of Tokyo Station, has an area of 210 hectares, and it is a government office area with a population of 200,000 in the daytime. As there are many state guests and government dignitaries visiting important institutions of the country in this district, we regularly conduct facility inspections in a systematic manner in preparation for terrorism such as intrusion into facilities via sewer pipes and dangerous acts. On the other hand, as many of the sewer pipes in this district exceeded the legal service life of 50 years, there has been concern about the deterioration in function at the time of earthquake. Liquefaction is also presumed in most parts of the district. For this reason, in this work, priority is given to 17 facilities (Table 1) and 6 km of emergency transportation roads both of which are important as recovery bases at the

![Figure 3: The Image about Countermeasures against Earthquakes in Tokyo](image-url)

Table 1: The List of 17 Facilities for Seismic Reinforcement of Sewer Pipes

<table>
<thead>
<tr>
<th>Number</th>
<th>Facilities</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>National Diet</td>
</tr>
<tr>
<td>2</td>
<td>Legislative Bureau of House of Councilors</td>
</tr>
<tr>
<td>3</td>
<td>Prime Minister’s Office</td>
</tr>
<tr>
<td>4</td>
<td>Board of Audit</td>
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<tr>
<td>5</td>
<td>Cabinet Office</td>
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<td>6</td>
<td>Financial Service Agency</td>
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<tr>
<td>7</td>
<td>Ministry of Internal Affairs and Communication</td>
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<tr>
<td>8</td>
<td>Ministry of Foreign Affairs</td>
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<tr>
<td>9</td>
<td>Ministry of Education</td>
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<tr>
<td>10</td>
<td>Culture, Science, Sports and Technology, Agency for Cultural Affairs</td>
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<tr>
<td>11</td>
<td>Japan Patent Office</td>
</tr>
<tr>
<td>12</td>
<td>Ministry of Land, Infrastructure, Transport and Tourism</td>
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<tr>
<td>13</td>
<td>Tokyo Metropolitan Police Department</td>
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<tr>
<td>14</td>
<td>NTT DOCOMO, Inc.</td>
</tr>
<tr>
<td>15</td>
<td>National Personnel Authority</td>
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<tr>
<td>16</td>
<td>Ministry of Health, Labor and Welfare</td>
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<tr>
<td>17</td>
<td>Ministry of Economy, Trade and Industry</td>
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</tbody>
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time of earthquake, and we decided to implement seismic reinforcement by TTSRC and TTMFP (Figure 4).

The details of the construction work are as follows:

Construction period: from 7 August 2015 to 5 July 2016, 220 days
Construction purpose: seismic reinforcement of sewer pipes in NKD
Target facilities: seismic reinforcement of sewer pipes receiving sewage from disaster recovery bases (17 facilities) and manhole floating prevention along 6 km of emergency transportation roads
Construction quantity: 131 locations for TTSRC and 47 locations for TTMFP

3.2. Challenges in Proceeding the Construction

In NKD, many underground buried objects are congested, and it has large traffic volume and many parked vehicles so that traffic regulation has been difficult. As the Diet, ministries and government agencies are located in this district, it was also requested to minimize the influence of construction as much as possible. On the other hand, other lifeline constructions and redevelopment projects were carried out within the same district, and the construction period and the working time were restricted when implementing the construction. In particular, due to the difficulties in coordination with government agencies and in traffic regulation, even during the construction period, it was required to implement the construction on holidays or between 21:00 and 06:00 with less traffic volume. Furthermore, in order to avoid overlapping with other constructions, construction period was also limited at some construction sites. In response to such site conditions, ingenuity of the construction method was required in order to complete the construction within the initial construction period.
3.3 Approaches
Specifically, we addressed the following 3 points to solve the above-mentioned challenges.

3.3.1 Gathering Construction Process in Three Areas
First, we tried to speed up the work by reducing the work waiting time and travel time. TTSRC has 4 main stages in its process, namely (i) invert chipping, (ii) cutting, (iii) sealing, (iv) invert restoration, and each stage requires different equipment to be used and technical experts.

In the construction procedure at the design stage, it was planned to complete the work on manholes one by one by replacing equipment to be used and replacing workers for each stage. Movement between construction sites would also create a loss of time.

However, in practice, for 100 sites excluding the overlapping sites out of the 140 sites subject to construction, considering the maximum amount of work per day, we divided the construction range into 3 blocks(Figure 5) and increased the number of work units at one time up to 3 at the maximum.

The same work was done continuously in a few days within one block and after the work was completed, the team moved to the next block so that the work process transferred not for each manhole but for each block. By reducing time for retooling equipment to be used and time for shifting workers, we reduced the waiting time and travel time for work, made full use of working time, and improved work efficiency. As a result of preparing the single work process, the amount of work per day increased and the construction period could be shortened.

3.3.2 Assembling the Cutting Machine in the Factory
Secondly, by assembling the equipment outside the construction site and loading it to the site, the work at the site became more efficient. In the case of TTSRC, cutting equipment is normally assembled on site.

For the construction this time, as the working time at the site was limited, we made it possible to secure longer time for working on site by assembling equipment in advance at the factory and loading it to the site.
3.3.3 Minimizing the Working Zone

Thirdly, for 40 sites overlapping with other construction works, we narrowed down the working zone and realized competing constructions. In order to perform on-road construction, it is required to reduce the influence on road traffic. In particular, if the working zones are adjacent to each other, they would become an obstruction to road traffic and it might be impossible to get permission for construction from the traffic administrator.

For example, for TTSRC, a work area of 25 m² is required at the time of construction. In order to implement construction at the same time at two adjacent places, it has been required to separate them more than 300 m between each other. In order to realize the construction at the adjacent places this time, we parked the work vehicle carrying the equipment to the work zone at another location and reduced the work area to 10 m² (Figure 6, Picture 6). By reducing the influence on road traffic, we could obtain the understanding of traffic administrators and carry out competing constructions.

In this construction work, we tenaciously consulted with concerned organizations in NKD and competing construction providers, and adjusted the construction date, construction time, construction sites to prepare conditions for launching the work on site. In addition, by making full use of the features of the trenchless technology of seismic reinforcement technology, we minimized the influence on road traffic and the surrounding environment. We also worked on ingenuity at the work site and completed the work by shortening construction period.

4. Conclusion

TMG has been making its efforts in realizing an earthquake resistant town in preparation for an epicentral earthquake directly under the capital which is expected in the future. Considering the priority of target areas and target facilities, the Bureau of Sewerage is promoting countermeasures for sewer pipes against earthquake by actively utilizing TTSRC and TTMFP that can be implemented while draining sewage without excavating the road.
In the future of NKD, we will work on earthquake resistance of the whole sewer pipes throughout the area for 3 years starting from 2021 to improve earthquake resistance of the entire area. In addition to this, the Bureau of Sewerage will implement seismic reinforcement of the sewer pipes for 2000 facilities in the Metropolis and manhole floating prevention for 750 km of roads for 5 years starting from 2016. We will continue to steadily promote earthquake resistance of sewer pipes and will further enhance the safety and security of the capital Tokyo.

References
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