Construction of City Gas-Trunk Line by Shield Tunnelling Method in the Deep Underground of Metropolitan Tokyo

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ABSTRACT

The current problems of road construction in Metropolitan-Tokyo are the heavy traffic jam, the complication with an existing other infrastructure, for instance power supply cables, the pipeline of water supply, and drainage, etc., and this evasion when dig-up works in the shallow underground. Furthermore, if the safety improvement of a social infrastructure for the large earthquake-disaster of Japanese peculiarity is considered, the depth extends to the stratum of stable-foundation ground. We introduce "The pipeline construction by shield tunneling method in the deep underground", called "Chuo(Central) trunk line (23 km, Depth: ave.40~50m, max 65m)" that runs through the center of Metropolitan-Tokyo, for the natural gas supply while solving these problems. The tie-in of the project will be September, 2009.

1. INTRODUCTION - HISTORY OF GROWTH IN TOKYO GAS TRUNK LINE NETWORK

Tokyo Gas established an infrastructure enabling them to keep up with demand around the year 2000, through three major projects conducted during the period from the 1960s to the 1980s. These projects were the operation to add change in gas calorie, the construction of LNG base and the construction of the Circular Line. This is the period of phase I facility development. The Circular Line is composed of the line with the design pressure of 7MPa which originates in the Sodegaura LNG Terminal, and the 2~3MPa line which originates in the Negishi LNG Terminal and serves as the foundation of Tokyo Gas in the trading area within 30km from the Tokyo metropolitan district. The 7MPa line, which consists of the Chiba Line and the Saitama Line surrounding the area within a 30km radius from central Tokyo and the Submarine Line to deliver gas straight to the center of demand in urban core, displays great long-range gas transportation capability, and is suitable for transporting a large volume of gas. On the other hand, the 2MPa line which originates in Negishi LNG Terminal is composed of the Negishi Line and the Second Negishi Line, and is an important supply source for Kanagawa and the Western Tokyo area. Due in part to the effect of change added in calorie, the actual gas flow rate running through the pipeline network has barely increased from 1978 to 1988, when the calorie change was completed. Consequently, the gas supply system that could cope with increases in gas sales volume without a substantial amount of additional investment and backed by the abundant transport capacity of the Circular Line had been sustained for about twenty years.

In addition, the twenty-year period between 1985 and 2005 can be positioned as phase II facility development of the network infrastructure, including the high-pressure trunk line that is the operational base of Tokyo Gas. Completion of calorie change in 1988 as well as smooth acquisition of and increase in demand of wholesale trade for large industry use and for gas providers in surrounding area led to a significant increase in the volume of gas transportation, which peaked in 2000 when it reached 1.6 times the level in 1990 (annual growth rate of more than 5%). It was made clear in 1992 that the transport capacity of the Circular Line would drop at some point based on the estimates for
demand over a long/ultralong period of time, looking ahead to 2000 and later years. To deal with this situation, the company took measures to enhance the capacity of the Circular Line including the Second-Chiba Line. Furthermore, lines which extend to the Saitama/Tochigi and Ibaraki regions from Circular Line were constructed to meet local demand.

Fig. 1. Tokyo Gas pipeline network.

Later, lack of capability in the Circular Line became obvious due to construction of the lines to meet local demand extending to surrounding areas from the 7MPa line and deficiency in supply capability of the 2MPa line. As a countermeasure against this, an optional enhancement of facility such as a base outside of a bay and a storage facility was studied as well. In the end, however, following a significant cost reduction in shield construction, the conclusion reached was the plan for the Chuo Line (Kasai ~ Soka) to facilitate stable supply at minimum cost and in the most reliable manner. In respect to the formation of pipeline network of Tokyo Gas, the Chuo Line is positioned as a line to introduce gas of the Submarine Line, which has abundant capacity, into the Saihoku Line which is the source to transport gas to a wide area in the north at the shortest distance.

2. DIFFICULTIES IN CONSTRUCTION AND MANAGEMENT OF PIPELINE IN CITIES

In big cities such as Tokyo, excessive congestion produces difficulty in construction of high-pressure pipeline. The primary difficulty lies in its procedures. In Japan, almost all the gas pipelines are installed beneath streets. In the case of Tokyo, when deciding the utilization of underground spaces beneath streets, the “Council Coordinating the Utilization of Underground Space below Streets in Tokyo” is held mainly by road administrators, where underground work operators, road administrators and railroad administrators, among others, meet to exchange extra-long-term plans and share information. In the event of large-scale and long-extended pipelines such as high-pressure pipelines, an entry should be made to the aforementioned council at the planning stage to make the intention clear. When the plan is brought into shape, we will have consultations with the City Planning Bureau, etc., confirm the presence of an extra-long-term project of large-scale railroad, sewage, etc., and design the layout to have the pipeline constructed in the location that interferes with other projects as little as possible. Further, adjustment will be made with other underground work operators and railroad and other
administrators to arrange the long-term projects of the respective entities. Then, occupancy of roads will be applied for after discussing with the appropriate road administrators. Construction can commence only after permission is given. In this way, overcrowding of underground space creates the necessity for coordination among a number of future plans. In the event of shield tunnelling method, change of the depth facilitates the abovementioned coordination.

What becomes a problem when designing an actual plan is the congestion of other underground installations. Below most of the major roads in Tokyo, there already exists the infrastructure of gas along with water supply and sewerage system, electricity, telecommunications, etc. When cut and cover construction is implemented, the work needs to be accomplished around the existing infrastructure and it is remarkably difficult to find space. The figure on the right shows an example of congested situation of other underground installation. On the other hand, when shield tunnelling method is employed, spaces below these congested underground installations can be occupied and thus it facilitates avoidance of other underground installations.

What presents the second problem is transportation condition on the street. When cut and cover construction is conducted, traffic needs to be controlled. Due to generally heavy traffic during daytime in this area as indicated in the picture on the right, construction is conducted during nighttime hours when there is less traffic. However, as for the high-pressure pipeline construction, it is impossible to complete a series of processes ranging from excavation to pipe work, welding, inspection, back-filling and tentative restoration with night-time construction alone. Thus, generally, a permanent working zone (day-and-night continuous traffic control) is indispensable. The possibility that the traffic administrator – the police – will allow such conditions on major streets is slim. In contrast, in the event of shield tunnelling method, it is possible to conduct construction without blocking road traffic.

As just described, there are several elements that complicate high-pressure pipeline construction in cities. As for the construction of the Chuo Line, employment of non-open-cut shield tunnelling method solved these problems and enabled an ultra-extended high-pressure gas pipeline to be constructed in Tokyo, which is one of the largest cities in the world.

3. GEOLOGIC CONDITION IN TOKYO

With regards to overall geologic formation related to the route of the Chuo Line, the area is sandwiched between the Arakawa River on the west side and the former Edogawa River on the east side, which is a low flat land located in the eastern part of “low-lying downtown Tokyo.” In this area, the vicinity of the starting point of gas pipeline on the south side is located in a landfill and a reclaimed land of a relatively new age (see figure 4 on the next page).

The geologic condition under the ground in this neighbourhood consists of Early Pleistocene, Kazusa Group, Middle Pleistocene, Edogawa Formation and Tokyo Formation, Late Pleistocene alluvial terrace deposit and Late Pleistocene to Holocene alluvial formation (Nanagochi Formation and
Yurakucho Formation) in order from the bottom. Table 1, below, describes the characteristics of the geologic layer subject to the project that passed recently. The following indicates the overall longitudinal map of the Chuo Line. The layers consist of the Yurakucho Formation (yellow), Nanagochi Formation (light blue), and Tokyo Group (brown and blue) in order from the top.

![Fig. 4. Geographical features in Tokyo.](source)

Table 1. Characteristics of the geologic layer in Tokyo.

<table>
<thead>
<tr>
<th>Geologic layer name</th>
<th>Upper Yurakucho Formation (Yu)</th>
<th>Lower Yurakucho Formation (Yl)</th>
<th>Nanagochi Formation</th>
<th>Tokyo Group (Takasago Formation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer thickness</td>
<td>About 5-10m</td>
<td>About 20-30m</td>
<td>About 10-30m</td>
<td>About 30-50m</td>
</tr>
<tr>
<td>Facies</td>
<td>Loose sand and sand gravel</td>
<td>Homogenous clay</td>
<td>Sandy clay, sand/clay alternate layers</td>
<td>Alternate layers of sand, clay and gravel</td>
</tr>
<tr>
<td></td>
<td>Big facies change</td>
<td>Small facies change</td>
<td>Indicates thin-bedded structure</td>
<td>Relatively big facies change</td>
</tr>
<tr>
<td>Fossil</td>
<td>Shell incorporation</td>
<td>Shell incorporation</td>
<td>Humic matter incorporation</td>
<td>Shell is incorporated frequently</td>
</tr>
<tr>
<td>N value</td>
<td>Sand --- 5-10</td>
<td>0-2</td>
<td>Sand --- 10-30</td>
<td>Sand --- 30-50 and more</td>
</tr>
<tr>
<td>Sedimentary setting</td>
<td>Neritic nature</td>
<td>Neritic nature (inner bay nature)</td>
<td>Fresh water ~ brackish nature</td>
<td>Neritic nature</td>
</tr>
</tbody>
</table>

Source: Tokyo Metropolitan Institute of Civil Engineering: Overall Ground Map of Tokyo (Partial addition is made)

![Fig. 5. The overall longitudinal-section map of Chuo gas-trunk line.](source)
4. MAIN POINT OF TECHNICAL CRITERIA UNIQUE TO JGA AND TG IN RELATION TO TRUNK LINES

The “Guideline for High-Pressure Pipeline” (The Japan Gas Association (JGA)) is a public guideline related to high-pressure trunk lines. This guideline is composed of roughly three pillars, which are “design,” “construction” and “operation and maintenance.”

“1.5 Selection of High-pressure Pipeline Route” indicates the guideline for selecting the optimal route in view of safety, ease of operation and maintenance, simplicity of construction, economic efficiency and other factors. Although this is the description targeting general cut and cover construction, the selection criteria are slightly different when employing deep underground occupancy through shield tunnelling method. For example, relatively little impact is given by the condition of existing underground installations and traffic condition on the street, among other factors. However, there exist unique check points including (1) whether there is a sufficiently large area of land (approximately 2,000m$^2$) that can be used as the place to build a shaft to start moving shield in several locations along the route, and (2) whether curvature above a certain level can be secured. In the case of the Chuo Line, several locations were listed as the candidates for two sites to build shaft along the route at the stage of selecting a route. Further, with the goal of avoiding the existing underground installations, it was determined to occupy deep underground with average earth covering of about 40m. With regard to materials in “2.2 Materials and Junction,” “X42 ~ X65” grades are regulated for “API 5L line pipe” to be normally used as the material of high-pressure pipeline. These are incorporated in the Gas Utility Industry Law in which mechanical property is regulated for each grade. However, Tokyo Gas (TG) puts “TOPERS” into practice. “TOPERS” is the company’s original criteria that have additional regulations to improve quake resistance, etc. Further, for connection, highly reliable welding connection is employed. While quality is confirmed by the “welding procedure” regulated in the Gas Utility Industry Law, the original welding procedure is regulated in “TOPERS” and put into practice as in the case of materials, which realizes higher quality pipelines.

“2.3 Structural Design” indicates the guideline for design for appropriate structure for various kinds of load applied on high-pressure pipeline. Of the load applied on a regular basis, the key factors to determine the thickness of pipe are inner pressure and earth pressure, and the computational formulas for both of them are indicated in the Gas Utility Industry Law. As for the inner pressure, the thickness of pipe required to withstand gas pressure of up to 7MPa is calculated. On the other hand, the earth pressure is based on the thinking that the weight of the earth is placed entirely on the gas pipe, or what is called the “earth pressure of complete covering.” In the event of shield tunnelling method, consideration is given in line with the “Standard Tunnel Specifications” to realize the structure that enables earth load to be borne at a tunnel segment. This leads to the situation where only the inner pressure should be considered for gas pipes. Further, according to the “Standard Tunnel Specifications,” the thinking of what is called “loosened earth pressure” can be applied if the ground is stable. Consequently, all that needs to be considered is the earth pressure that is twice as much as the outside diameter of a tunnel, which will enable the economical design of the segment. Since the major part of the eastern Tokyo is alluvial plain, it was decided that the Chuo Line would occupy the deep underground area with an average earth covering of about 40m in an effort to drill stable ground. As Japan is an earthquake-prone country, it is necessary to confirm whether gas pipes are safe in the case of a massive earthquake. The Gas Utility Industry Law obliges companies to design high-pressure pipelines in accordance with the “Guideline for Earthquake-resistant Design of High-pressure Gas Pipelines” and the “Guideline for Liquefaction and Earthquake-Resistant Design of High-pressure Gas Pipelines” (both The Japan Gas Association). The Chuo Line is noticeably favourable in terms of earthquake-resistant design, due to a deep underground location that will hardly be affected by earthquakes, and requires no consideration of lateral flow from liquefaction.
5. CONSTRUCTION OF CHUO LINE

To construct the Chuo Line, a tunnel about 2m in diameter will be built by the shield tunneling method, a gas pipe about 600 mm in diameter laid within the tunnel and then the gap filled with air mortar. The typical cross-section drawing is indicated in figure 6. At Tokyo Gas in recent years, the filling method mentioned above has become mainstream. In some other infrastructures (electricity, telecommunications, etc.), however, methods that do not employ fillings serve as the mainstream. If a gas cable tunnel is not filled, the cross section must be widened in order to secure the inspection space. In addition, it will be necessary to install an inspection corridor, ventilation facilities, lighting system, gas detector and other equipment, along with mandatory countermeasures against expansion and absorption of a gas pipe caused by temperature variation, among other measures, which will lead to an increase in the initial costs. Filling can generate almost the same situation as buried tunnel, and thus the daily checking procedure can be eliminated. As a result, it can be highly earthquake-resistant and maintenance-free. Therefore, the filling method has entered the mainstream of Tokyo Gas’s pipe laying within a tunnel in recent years.

Since the shield of the Chuo Line is constructed in an urban area, a lot of leading-edge technologies have been incorporated. Firstly, state-of-the-art technology is used to realize small caliber and long range. Since other existing underground installations are congested below streets in urban areas, a shaft needs to be built in private land. However, vacant lots can hardly be found in bulk in actual situation. To cope with this, we conducted long extended drilling ranging 6.3km, which is unprecedented and the longest of a small caliber shield in the 2m level. Further, we employed the technology for underground junction at deep underground area that is covered with at least 40m of earth and is subjected to high underwater pressure, and because two places along the line are used for building shafts for departure from both sides, the longest distance between shafts was able to be extended to 11.1km. This resulted in facilitating the construction with a remarkably small number of shafts; that is, three starting shafts along the overall length of 23.1km. Secondly, advanced technology enabled ultrahigh-speed drilling. Introduction of a broad range of technologies to enhance the performance of the shield tunnelling machine (fig. 7) and improve the efficiency of transporting materials (mainly tunnel segment) actualized high-speed drilling to proceed at 400m/month on average. Due to the employment of a number of cutting-edge technologies like those described above, drilling of a total of five shields for the Chuo Line completed in March 2007.

REFERENCES