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The Niigata-Sendai Gas Pipeline Project was successfully completed in 1996. This is the second longest gas pipeline that crosses the Japan Islands with a diameter of 20 inches and a length of 251 km. Japan Petroleum Exploration Co., Ltd. transports natural gas, which is domestically produced at offshore fields near Niigata pref. or imported as LNG from Indonesia to the Shin-Sendai Thermal Power Plant of Tohoku Electric Power Co. Inc., through this pipeline. Kawasaki Steel had been engaged in this project from the preliminary investigation and planning phase for realization of the project and contributed to the construction of 97 km, 39% of the total length. Kawasaki Steel introduced various advanced technologies to the construction for securing safety and efficiency. This report refers to the outline of the project and some typical advanced technologies.

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1 Introduction

The Niigata-Sendai Gas Pipeline was constructed to supply the Shin-Sendai Thermal Power Plant of Tohoku Electric Power Co., Inc. with a mixture of natural gas, which is domestically produced at offshore fields in Niigata Pref. by Japan Petroleum Exploration Co., Ltd., and gasified LNG, which is produced at Arun, Indonesia and unloaded at Niigata-Higashi Port. This is a long-distance high-pressure gas pipeline with a total length of 251 km and is regarded as the first embodiment of the national gas pipeline concept, in recent years. The construction of this pipeline was successfully completed in March 1996 and it is operating smoothly. Kawasaki Steel participated in this project at the preliminary investigation and feasibility study stage, which started in 1986. In the construction stage started in 1992 after seven years of investigation, planning, design and negotiations with local governments and residents, the company carried out the construction of a 97 km length of pipeline corresponding to 39% of the total length. In this project, safety and construction efficiency were the main themes and the development and introduction of the latest technologies were pushed to realize them. This report describes the project and typical examples of the pipeline construction technologies applied.

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2 Outline of Project

2.1 Specification of Pipeline

The general route of the pipeline is shown in **Fig. 1**. This pipeline is a long-distance high-pressure trunk line with a total length of 251 km that starts from Niigata-Higashi Port at Shiunji-machi, Niigata Pref. and terminates at the Shin-Sendai Thermal Power Plant of Tohoku Electric Power Co., Inc. in Sendai City, Miyagi Pref. The main specifications of the pipeline are shown in **Table 1**.

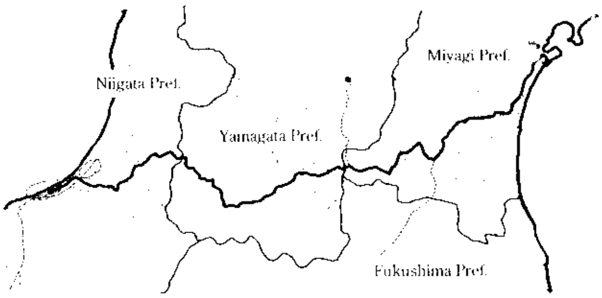

Fig. 1 Route map of natural gas pipeline from Niigata to Sendai

Table 1 Outline of Niigata-Sendai Gas Pipeline

Total pipeline length (km)	251
Total pipe weight (t)	36 500
Design pressure (MPa)	6.86
Diameter (mm)	508.0
Wall thickness (mm)	11.91
Grade	API 5L X60
Regulation	Mining law
Design standard	Technical guideline for high pressurized gas pipeline
Transmission capacity (Nm^3/d)	5 000 000

This construction project was carried out under the stipulations set forth in the Mining Law and Mine Safety Law. In order to increase the safety of equipment, the "New Technical Guidelines for High Pressurized Gas Pipeline[1]" prepared by the relevant authorities, experts, and experienced technicians were adopted as technical standards.

2.2 General Work Schedule

The general work schedule of this project is shown in **Fig. 2**. This project took about 10 years from planning to start of service: 3 years for investigation and planning, 4 years for design, approval, etc., and about 3 years for construction. Thus we can see that preparations such as preliminary investigations and obtaining various permits are very important.

2.3 Required Performance of Steel Pipe

The steel pipe used in this pipeline was required to provide sufficient mechanical strength to prevent pipeline failure, and high weldability for improving the construction efficiency. Performance tests, especially for the former, were conducted to prove that both base metal and weld zone would meet the required values shown in **Table 2**.

Table 2 Mechanical properties

Grade	API 5L X60
Charpy energy (V notch) (J)	35 (at −10°C)
DWTT Percent shear area (%)	40 or more (piece) 80 or more (ave.)
Hardness (Hv)	250 or less

2.4 Pipe Burying Work

The right of eminent domain in Western countries, which is favorable for public pipeline construction, is not well established in Japan. Therefore, it is necessary to bury piping under public roads, as a rule. Accordingly, pipe burying work was carried out by providing 50 to 100 m long work zones on one side of a road. The normal section of a work zone is shown in **Fig. 3**. Work progressed at an average rate of 15–25 m/d.

2.5 Work for Special Portions

In selecting the pipeline route, efforts were made to minimize the amount of work for special portions, i.e., crossing portions such as rivers and railroads. Nevertheless, it was necessary to execute work for 62 special portions in the construction section of Kawasaki Steel. In such special portions, an optimum process was selected, in consideration of the surrounding conditions, from

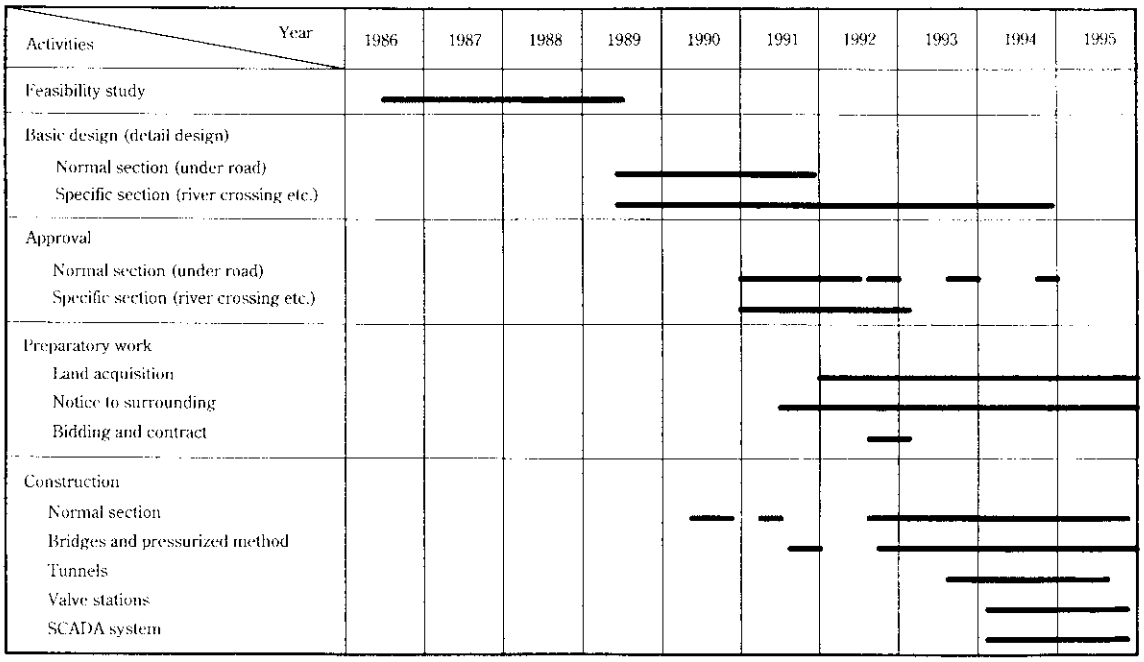

Fig. 2 Project schedule

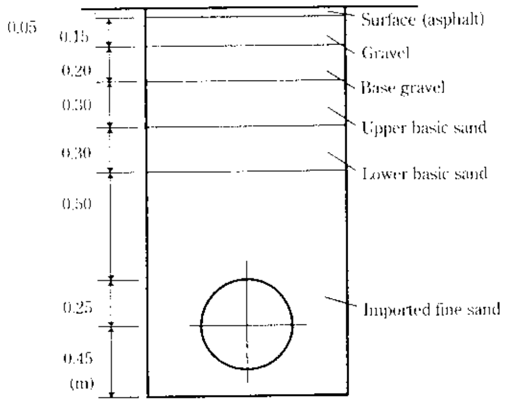

Fig. 3 Normal section (under road)

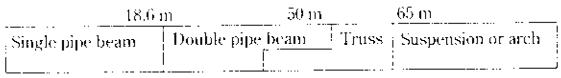

Fig. 4 Bridge style and span

Table 3 Pipeline bridges style

Additional pipeline to existing briges	
Existing bridges	5
New walking bridge	1
Exclusive pipeline bridges	
Pipe beam bridge	10
Truss bridge	4
Pipe arch bridge	1
Suspension bridge	1

among various processes such as erection of an exclusive pipeline bridge, installation onto an existing bridge, underground pushing and construction of an exclusive pipeline tunnel.

2.5.1 Bridging

When crossing by a bridge is necessary, the most economical process is the installation onto an existing bridge. However, when this process is impossible, it is necessary to erect an exclusive pipeline bridge. In this case, which type of exclusive pipeline bridge should be selected is an important point of planning and design that affects the economical efficiency of the project. In this project, the bridge types shown in **Fig. 4** were adopted and selected according to the span length. Especially in the crossing portions of relatively short span length, such as small rivers and water channels, short construction periods and high efficiency were achieved by using the pipe beam type. In selecting this type, wind oscillation and free vibration experiments conducted beforehand showed that there were no structural problems. The bridge types adopted are shown in **Table 3**. An example of a suspension bridge is shown in **Photo 1**.

2.5.2 Pushing

Pushing was adopted when crossing by a bridge

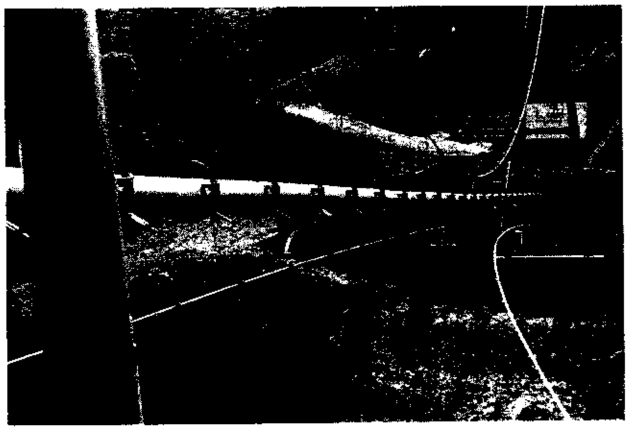

Photo 1 Kosutegawa River Suspension Bridge

Table 4 Micro tunneling and pushing

Style	Distance (m)	Numbers
Micro tunneling (large scale)	40–150	4
Pressurized super slurry method	187	1
Micro tunneling (small scale)	10-80	12
Horizontal boring pushing	6.0	1
Horizonger pushing	6.0–35	13
Grundoram pushing	6.0–14	4
Simple pushing	4.0–8.0	4

was economically disadvantageous or was impossible due to river management regulations or other conditions. As shown in **Table 4**, optimum processes were selected in consideration of the pushing distance and soil conditions.

2.5.3 Tunneling

The Niijuku district, located at the boundary between Yamagata Pref. and Miyagi Pref., is a rugged mountain district. The excavation of a tunnel with a total length of 1 027 m was planned because pipe laying by tunneling here was more economical than the general pipe burying process. The TBM (tunnel boring machine) process was adopted because in this construction section it was necessary to conduct inclined boring with a grade of 12%, and a horizontal bend was present in the middle of the construction section. This process has high construction accuracy and is suitable for inclined boring as in this construction section. The excavation rate was about 10 m/d. The inside of the tunnel after pipe laying is shown in **Photo 2**.

2.6 Electrical and Instrumentation Works

A SCADA (supervisory control and data acquisition) system was adopted as the monitoring and control system. Two monitoring centers, one in Nagaoka and the other in Sendai, were installed in consideration of the redundancy for earthquakes, and stream conditions and safety preservation data are gathered in real time through wireless circuits and NTT dedicated circuits from 24 of the many emergency shutdown valve stations

Table 5 Result of mechanical tests

	Mother pipe	Bend pipe
Tensile strength (N/mm²)		
Compression	—	637.0
Tensility	—	627.0
Neutrality	607.0	614.0
Charpy energy (mean) (J)		
Compression	—	100.0
Tensility	—	109.0
Neutrality	121.0	102.0

increase and for the Charpy energy to decrease due to the occurrence of work hardening. However, the absolute levels of these changes produced no problems and it was verified that these values adequately met the specifications of this pipeline. For the anti-corrosive coating of steel pipe, no effects of cold bending on either appearance or bonding strength were observed.

3.2 Development of Work Management System for Long-Distance Pipelines

3.2.1 Outline

In managing the construction of the long-line pipeline, it was necessary to solve the following problems unique to long-line pipeline work:

(1) Multiple site offices simultaneously execute the work for each construction section, which is the minimum unit of work, and these site offices are located over a wide area.

(2) The number and location of site offices change with the completion of the work in the relevant construction section.

(3) The information on the construction management generated at these multiple construction sites is immense and it is necessary to coordinate the site offices according to the progress of the work.

It was considered difficult to solve the above problems by employing the conventional system in which the construction process is managed in site-office units. Therefore, the quality of work was maintained and schedules were efficiently managed by installing a supervisory site office to oversee all other site offices and by developing and applying a work control system for long-distance pipelines for the integrated control of immense information.

3.2.2 Features of system

This system has the following features:

(1) The digitization of work information enables the latest information to be integrally controlled, reducing the storage space needed and preventing the loss, deterioration and duplication of information.

(2) The adoption of notebook (or laptop) PCs as field terminals and personal computer communications using public telephone lines provided for greater flexibility and economy.

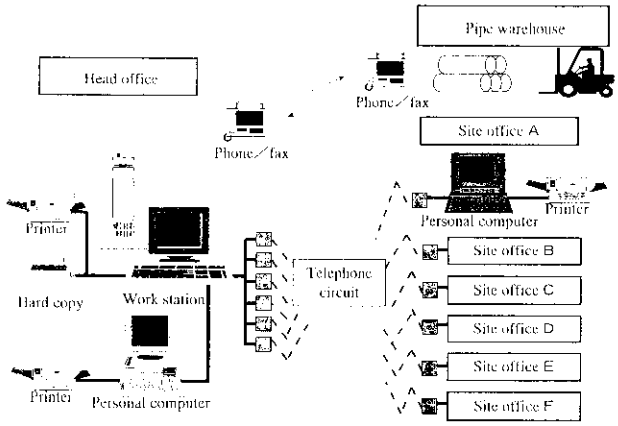

Fig. 8 Configuration of hardware

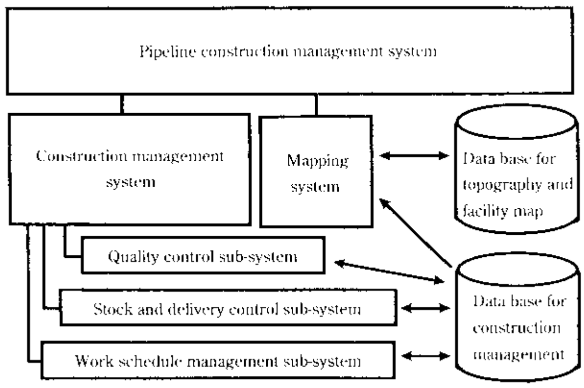

Fig. 9 Configuration of software

(3) Commercial software was effectively utilized for functions such as calculations, graph manipulation and statistical processing, helping to reduce development costs.

(4) EWS was adopted as the central control computer. The linkage of this computer to a mapping system enabled the progress of the work to be visually grasped on maps.

(5) It was possible to create an environment in which raw data accumulated every day during construction could be supplied to the client as maintenance control information after completion of the project.

3.2.3 Hardware configuration

The hardware configuration of this system is shown in **Fig. 8**. This system uses a control computer installed in the supervisory office as the key station and is composed of personal computer terminals in multiple site offices that are installed, transferred and removed according to the progress of the work and communication devices (modems) for connecting key station and terminals by telephone circuits.

3.2.4 Software configuration

As shown in **Fig. 9**, this system is composed of a stock and delivery control subsystem, a quality control subsystem and a work schedule management subsystem. The functions of these subsystems are described in detail below:

(1) Stock and Delivery Control Subsystem

5 kinds of steel pipe were used in this project; straight pipe, field-bent pipe, induction-bent pipe, induction-bent S-pipe, and short pipe. There were many kinds of bends because there were various combinations depending on angle and position of welded seam. In order to prepare these steel pipe materials in required quantities and at necessary places according to the progress of work, it is necessary to make accurate fabrication plans and service plans and to sometimes corrects these plans moment by moment. This subsystem controls the distribution information, inventory information and record information of these steel pipe materials, thus helping to facilitate material procurement.

(2) Quality Control Subsystem

In the construction of a high-pressure gas pipeline, the management of work in welded joints and of inspection results is very important for quality control. This subsystem controls the information on the conditions during welding, such as weather and the welders who conducted the welding, information on the results of appearance inspection, and information on the results of X-ray examination. When even a slight trend toward quality deterioration was observed, efforts were made to clarify the cause, thereby helping to maintain the level of quality.

(3) Work Schedule Management Subsystem

In each field office, the daily progress of the work was reported in the format of a daily work report. This subsystem gathered and controlled this format in an electronized form, put the information of all work management offices together and evaluated the information on the progress of work in terms of temporal or positional change for each construction section. In particular, the monitoring of the transition of work progress rate by statistical processing and the grasping of the positional degree of progress using a mapping system permitted quick planning and implementation of measures to change the manpower allocation and work schedule in consideration of the progress of the overall project.

3.3 Commissioning and Design Verification

3.3.1 Outline of commissioning

The Sendai-Shinko Port valve station (VS) located at the terminal of this pipeline system is an important facility that differs from other valve stations in that it controls the pressure of the gas transported from Niigata after dehydration and removal of contaminants and transports the gas to the Shin-Sendai Thermal Power Plant of Tohoku Electric Power Co., Ltd., the final user.

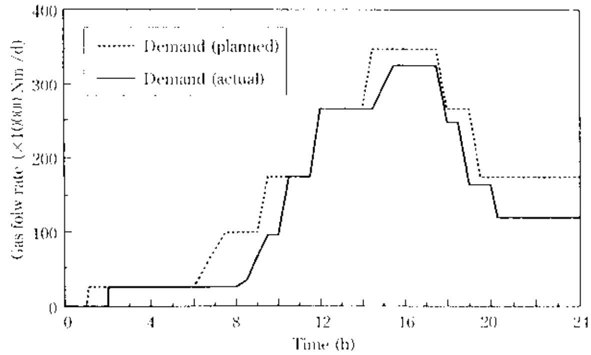

Fig. 10 Demand change of Shin-Sendai Power Plant

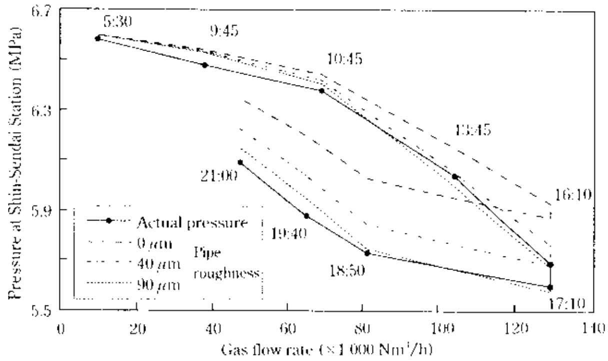

Fig. 11 Pressure change of Shin-Sendai Station

In the gas conveying and commissioning started on April 5, 1996, the air-tightness of the piping in this VS and the capacity of gas heating equipment were checked and the control parameters of pressure control valves were adjusted. At the same time, various gas feed date were obtained in order to verify the validity of the preliminary design. The evaluation of the transportation capacity of the pipeline was regarded as a particularly important item because the validity of the pipe diameter selected based on a study of an immense number of cases at the planning stage of the line was to be verified. This is because in general, the selection of a pipe diameter is an important factor that influences the commercial profitability of a long-distance pipeline construction project.

3.3.2 Evaluation of transportation capacity

The evaluation and examination of the transport capacity were conducted using an analytical technique on the basis of stream conditions data obtained during the test run. The 248.8 km long pipeline section from the start point at the Niigata-Higashi Port to the inlet of Sendai-Shinko Port VS was analyzed and the elevation of the line was also taken into consideration. **Figure 10** shows the demand change during the test run used as a flow rate boundary condition and **Fig. 11** shows the measured values of arrival pressure at the Sendai-Shinko

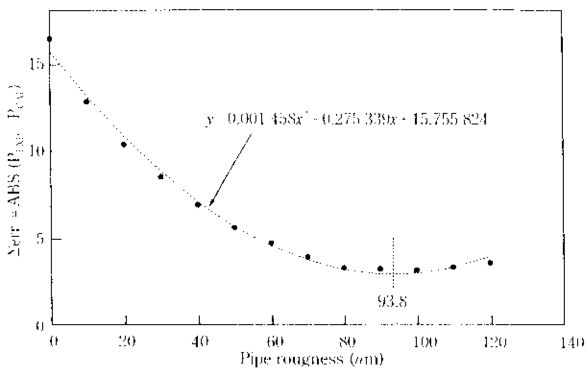

Fig. 12 Estimation of pipe roughness by simulations tuning

Port. It was found that the arrival pressure at Sendai has different values during a load increase and a load decrease, which can be generally shown as a hysteresis curve. Therefore, an unsteady oil feed simulation was conducted using the time load fluctuation, as a boundary condition and the flow during the test run was reproduced on a computer. Figure 11 shows a comparison between the calculations of arrival pressure at Sendai made using Colebrook's equation for estimating frictional loss on the basis of assumed pipe roughness values of 0, 40 and 90 μm and measured pressure values. As we can see, the calculated values of fluctuation hysteresis of arrival pressure at Sendai at each roughness were in good agreement with the measured values.

The pipe roughness at which the total sum of differences between measured and calculated values at each load level became minimal was then found by changing the estimated value of pipe roughness as shown in **Fig. 12**. Pipe roughness = 93.8 μm was obtained. This value is considerably larger than the roughness of general steel pipe because shape-induced losses, such as losses by bends and valves, are included in the frictional loss; therefore, this value is technically different from pipe roughness.

The efficiency of this line is about 0.95 when the pipe roughness of 25 μm generally adopted for new lines is used. The transport capacity was found by a steady-flow analysis using the pipe roughness determined in the above simulation and the start pressure at Niigata and the arrival pressure at Sendai as the boundary conditions. As a result, the transport capacity of this line was shown to be just slightly less than the estimated value at the initial design. This lower value might have resulted from additional pressure losses of solid-gas two-phase flow that occurred due to the splashing of ethanol injected at the start of operation of the line to prevent the generation of methane hydrate and absorption of the fine iron powder remaining in the pipe.

4 Conclusions

This paper has briefly described a construction project for a gas pipeline between Niigata and Sendai, including some of the principal technologies employed in this project to make the construction safe and more economical.

In Japan, demands are rising to construct and maintain natural gas pipeline networks as a key part of the infrastructure, as in the West. This pipeline is regarded as the first embodiment of this concept and the significance of the success of this project is very great.

Pipelines are very effective as a means of transporting continuous masses such as fluids; in this sense, the construction of a national pipeline system is a key part of Japan's infrastructure of the 21st century that can make a great contribution to the development of the country. The authors intend to make the best use of their experience with and results from this project to help achieve this goal.

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