Installation of Oxygen Submarine Pipeline in Mizushima Port*



Satoshi Maeda
Staff Assistant Manager, Pipeline & Water Works Engineering Sec., Engineering Div.

Akio Yokoyama
General Manager, Pipeline & Water Works Construction Dept., Kawatetsu Civil Engineering Co., Ltd.

Shinsuke Sakai
Staff Manager, Construction Steels Sec., Civil Engineering Dept., Engineering Div.

Synopsis:

In the installation work of the oxygen pipeline from Mizushima Works of Kawasaki Steel to Okayama Works of Tokyo Steel Mfg. Co., Ltd., a submarine pipeline was installed in the Mizushima Port by the floating tow method after various studies. A long and deformed pipeline was prefabricated on land according to specifications, equipped with floaters, launched, towed, and then sunk simultaneously at the time.

The pipeline consists of the service pipe whose nominal diameter is 200 mm and the steel jackets whose nominal diameter is 300 mm. The earth-covering thickness for the pipeline is 3 m. In design, the safety of the pipeline was especially confirmed by the dynamic analysis of expected stress of the pipeline during earthquakes. A large backhoe dredger equipped with spuds was applied for excavation of the seabed in order to remove hard sandy soil efficiently, and safety provisions, for example, large guardships, were sufficiently provided.

1 Introduction

Until recently, energy saving measures promoted by industrial circles have been on an individual company basis, and they appear to be gradually approaching their limits. Against this backdrop, a new type of energy saving measure is being investigated in the Mizushima district under the guidance of the Ministry of International Trade and Industry; measures going beyond individual enterprise basis and backed by a joint energy utilization scheme.[1]

This work, an installation of an oxygen pipeline from Mizushima Works of Kawasaki Steel to Okayama Works of Tokyo Steel Mfg. Co., Ltd. via Mizushima Port, has been carried out as one of the new energy saving measures. After detailed investigations, a submarine pipeline has been installed in Mizushima Port by the floating tow method. Since Mizushima Port is designated as an important port with substantial ship navigation, the work was considerably difficult. **Photo 1** shows the whole view of Mizushima Port.

This report describes (1) the important points of pipe design, (2) the problems in the dredging work and countermeasures, (3) an outline of a deep retaining wall construction work at the riser part at Tokyo Steel side, and (4) An outline from fabrication through installation of long pipe.

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2 Outline of Piping Work

2.1 Particulars of Piping

The pipe has a double-wall structure consisting of service pipe (inner pipe) and jacket (outer pipe).

(1) Design Pressure
  Inner pipe: 27.5 kgf/cm^2
  Outer pipe: 9.9 kgf/cm^2
(2) Pipe Specifications
  Inner pipe: 200A, STPG38 SCH80 bare steel pipe
  Outer pipe: 300A, STPG38 SCH40 polyethylene coated steel pipe (KPP)

2.2 Installation Order

In the submarine pipeline installation, the seabed was excavated, and the excavated trench was evenly sanded to make a piping bed. Then the long pipe prefabricated

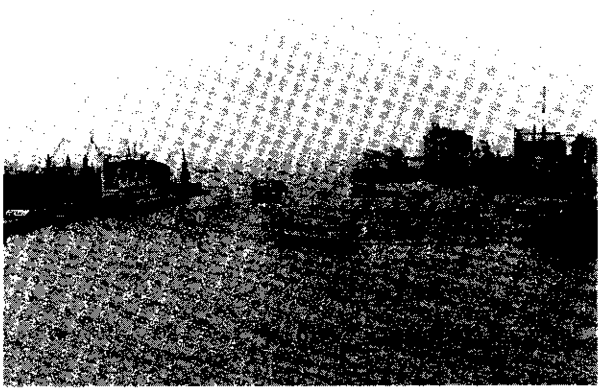

Photo 1 Mizushima Port

on land was launched, towed and sunk. The pipes were checked for their proper positions, and the trench was refilled.

The pipeline has two riser parts, one at Kawasaki Steel side, the other at Tokyo Steel side. The former was connected to the submarine pipeline through the pipe installed on the pipe bridge which was constructed above the sea level. For connecting the latter riser part to the pipeline, a part of the existing steel quay wall was destructed to raise the piping through it. After the pipe installation was finished, the quay was restored. **Figure 1** shows the flow diagram of installation, and **Fig. 2** the location of installation site.

2.3 Work Safety Assessment

Since the work had to be carried out in Mizushima

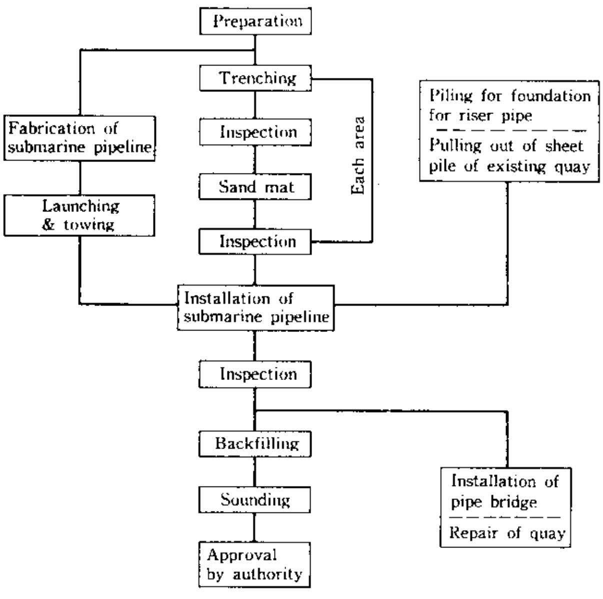

Fig. 1 Flow diagram of installation of submarine pipeline

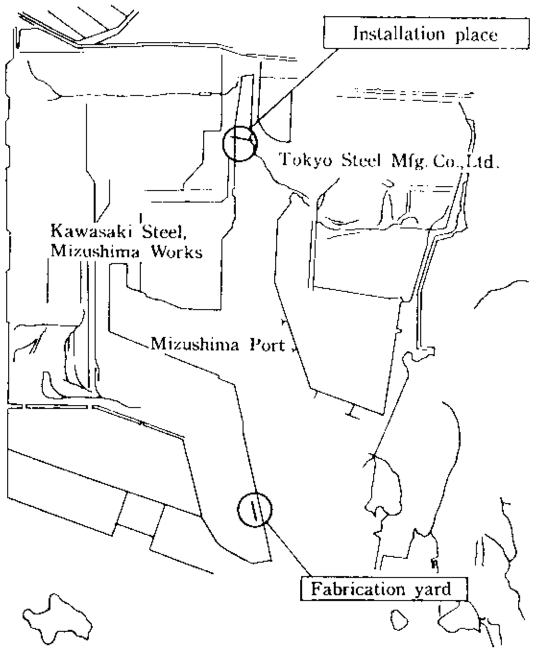

Fig. 2 Location of installation site

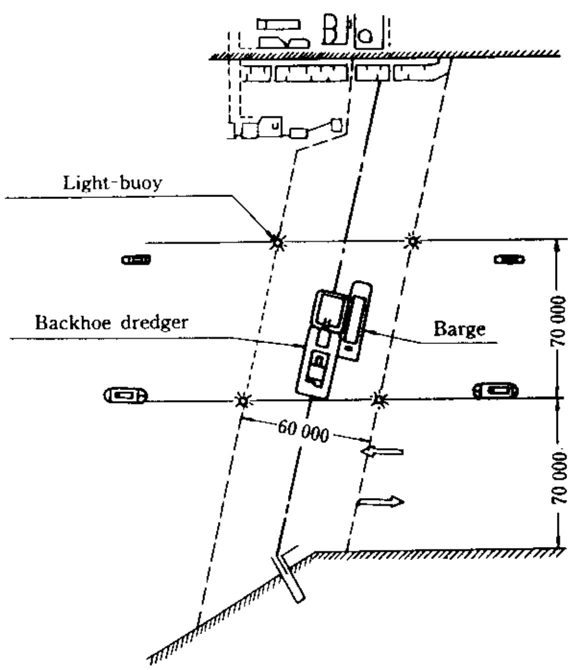

Fig. 3 Partition of installation area

Port which is a designated important port and has many navigating ships, a public institution, Setonaikai Navigation Safety Association, was consigned to assess the safety of the work and Special Committee for Navigation Safety Provisions was established for this work. As a result of the investigations[2], the working area was determined (see **Fig. 3**), and the arrangement of guardships was suggested. These determination and suggestion were observed in carrying out the work. Also, especially magnetism detection was performed as pre-investigation to see if there were any dangerous objects such as mines or blind shells.

3 Pipe Design

3.1 Purposes of Double-Wall Structure

This submarine pipeline has a double-wall structure with the following purposes:

(1) The inner main pipe which serves as oxygen pipe is protected by the outer pipe.

(2) Nitrogen gas is enclosed between the inner and outer pipes, and any leak from the inner pipe is detected by monitoring nitrogen pressures and oxygen concentration in the nitrogen gas.

The important points in the pipe design are to determine earth-covering thickness and to investigate the stress occurring in the pipe, and the design calculations were carried out only for the outer pipe because the inner one is protected by the outer one as described above.

3.2 Design Requirements

The pipe was designed mainly based on Technical Standards for Port and Harbor Facilities in Japan (Japan Port and Harbor Association) and the Pressure Gas Control Law (The High Pressure Gas Safety Institute of Japan). Important elements for design are as follows:

(1) Piping: 300A, STPG38 SCH40

(2) Anchoring: Anchors for 3 000 DWT class ships

(3) Soil properties: **Fig. 4**

3.3 Determination of Earth-Covering Thickness

Earth-Covering thickness was determined in the following order:

(1) Studying the Largest Ships Expected to Navigate

The largest ships were determined to be 3 000 DWT class according to the investigation of navigation course depth and currently navigating ships.

(2) Determining the Particulars of Anchors Used by the Above Ships

From the actual results table of ship types and anchor weights, and from the Stockless Anchor Table of Japanese Industrial Standards (JIS), the particulars of the anchors used by 3 000 DWT class ships are found as follows:

Weight: 2.1 t
Base length: 1.47 m (in plan view)
Base width: 0.57 m (in plan view)

(3) Calculating Penetration Depth in Anchoring

The value was calculated using the method of Nakayama et al[3], as shown below.

The anchor velocity at sea surface v_a (m/s) is determined by Eq. (1).

$$v_a = \alpha \sqrt{2 g x_1} \quad \cdots\cdots (1)$$

where,

α: Resistance coefficient of anchor chain (0.6)
g: Gravitational acceleration (9.8 m/s)
x_1: Drop height of anchor above sea level (m)

x_1 is assumed to be 3.5 m as 3 000 DWT class ships are considered, then $v_a = 4.97$ (m/s) is obtained.

The equilibrium velocity v_c (m/s) of anchors in sea water is calculated using Eq. (2), as follows:

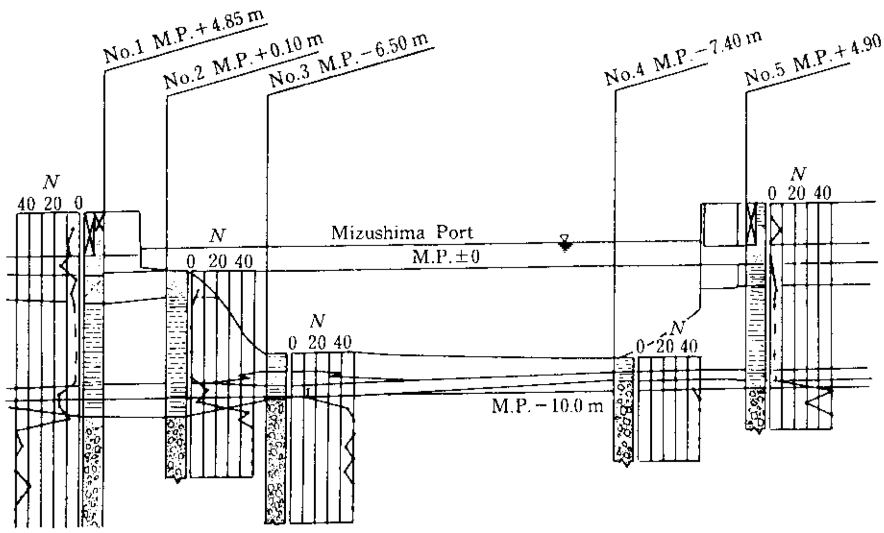

Fig. 4 Soil profile of the place where the pipeline was installed

$$v_c = \sqrt{\frac{A}{B}} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

$$A = \left(1 - \frac{w_o}{w_s}\right) g$$

$$B = \frac{w_o}{2W} \times C_D S$$

where,

w_o, w_s: Unit volume weights (kg/cm^3) of sea water and anchor, respectively

W: Anchor weights (2.1 t)

C_D: Resistance coefficient (1.2)

S: Projected base area of anchor (0.838 m^2)

From Eq. (2), $v_c = 5.87$ m/s is obtained.

The anchor velocity at seabed v_w (m/s) is calculated using Eq. (3) when $v_c > v_a$.

$$v_w = \sqrt{\frac{A}{B}} \tanh\left[\sqrt{AB}(t - C_1)\right] \cdots\cdots\cdots (3)$$

where,

$$t = \frac{1}{\sqrt{AB}} \mathrm{coh}^{-1} \exp\left[B(X - C_2)\right] + C_1$$

$$C_1 = -\frac{1}{\sqrt{AB}} \tanh^{-1}\left(\sqrt{\frac{B}{A}}\, V_a\right)$$

$$C_2 = -\frac{1}{B} \ln\left[\cosh\left\{\sqrt{AB} \times (-C_1)\right\}\right]$$

X means drop distance, assumed to be 11 m. From Eq. (3),

$$v_w = 5.87 \text{ m/s}$$

is obtained.

The penetration depth of anchor $\varDelta H$ (m) is calculated using Eq. (4) when the anchor is fallen on sand, and Eq. (5) when on cohesive soil.

$$\varDelta H = 0.382 + 0.0348 \frac{E}{S} \cdots\cdots\cdots (4)$$

$$\varDelta H = 0.520 + 0.235 \frac{E}{S} \cdots\cdots\cdots (5)$$

$$E = \frac{1}{2} \frac{W}{g} v_m^2$$

From these equations, the penetration depths are estimated as follows:

(a) When the anchor is fallen on sand soil,
$\varDelta H = 0.54$ m

(b) When the anchor is fallen on cohesive soil,
$\varDelta H = 1.55$ m

(4) Estimation of the Depth of Encroaching by Anchor Running

(a) When the Anchor Falls on Sand Soil and Moves on It

The encroaching depth was estimated using the results of anchor pulling test carried out by Second District Port Construction Bureau in October 1972. According to the test report[4], an anchor moves in sand soil and rotates around its axis in a slightly floated state, so that the depth of encroaching by anchor running will be equal to a half of the anchor head width. Therefore, in this case the encroaching depth is $1.47 \times (1/2) = 0.74$ m.

(b) When the Anchor Falls on Cohesive Soil and Moves on Cohesive Soil and Sand

The encroaching depth was estimated using the method by Kiyomiya et al.[5] In this case, the anchor moves almost horizontally in cohesive soil, and floats up by about $\frac{1}{2}H_0$ is sand when the running length is $2\sim3H_0$ (H_0 means anchor length, which is 2.31 m in this calculation). Since the moving distance in sand is equal to 4.7 m, the height of floating by anchor running is estimated at $\frac{1}{2}H_0 \times \frac{4.7}{2.5H_0} = 0.94$ m. On the other hand, the encroaching depth by rotation is equal to 0.74 m. Therefore, the anchor floats up by 0.2 m, the difference of above two values.

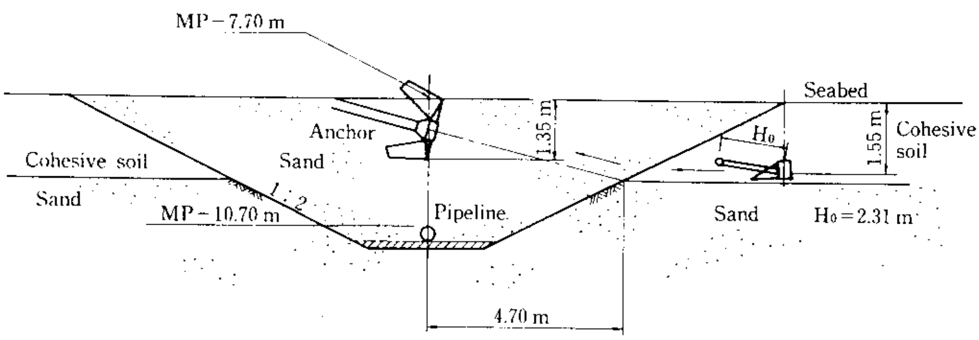

Fig. 5 Schematic illustration of expected anchor location, dropped on cohesive soil (case 2)

(5) Determination of Earth-Covering Thickness
The depth of penetration by anchoring and draging anchor is estimated as follows for the location where pipe is sunk:
(a) When the anchor falls on sand:
$0.54 + 0.74 = 1.28$ (m)
(b) When the anchor falls on cohesive soil:
$1.55 - 0.2 = 1.35$ (m)
Considering safety factors such as scouring by anchoring and previous examples, the earth-covering thickness was determined as 3 m.

Figure 5 shows the condition of an anchor when it is fallen on cohesive soil.

3.4 Examination of Stresses

The primary loads such as earth pressure, secondary loads due to earthquake or temperature variation, and pressures caused by the combinations of these loads in the pipeline were estimated. The most severe condition occurs during earthquake. Even in this case, however, the results are within allowable limits. The estimation process is omitted here, and only the results are shown in **Table 1**.

Table 1 Summary of stress calculations on submarine pipeline

	Load condition	Circumferential stress	Axial stress	Combined stress	Allowable stress
Principal load	Internal pressure ①	192	58	—	880
	Earth load ②	405	—	—	—
	Earth load (Earthquake) ③	444	—	—	—
	Water pressure ④	41	—	—	—
Secondary load	Dropped anchor ⑤	247	116	—	—
	Bucket ⑥	695	263	—	—
	Seismic force ⑦	—	942	—	—
	Thermal stress ⑧	—	378	—	—
Combination of each load	①+②+④	638	58	—	1 100
	①+③+④	677	58	—	1 870
	①+②+④+⑤	885	174	—	1 650
	①+②+④+⑥	1 333	321	—	1 650
	①+③+④+⑦	677	1 000	—	1 760
	①+③+④+⑧	677	436	—	1 375
	①+③+④+⑦	—	—	1 461	1 980

3.5 Dynamic Analysis during Earthquake

This analysis was carried out with the response analysis using El-Centro wave (case 1) and Hachinohe wave (case 2) as input seismic waves.

3.5.1 Soil conditions

Using the boring data of both seashores (1 site for each) and seabed (3 sites), and shear velocity data of the layer on land, the ground model and the necessary values were obtained. **Figure 6** shows the ground model.

3.5.2 Model for analysis

This model of the pipeline is about 280 m long with 33 nodes, and consists of 32 beam members.

3.5.3 Results of analysis

Table 2 shows the maximum stresses and **Fig. 7** an example of the results of this analysis. As is clear from

Table 2 Maximum stress in dynamic analysis of submarine pipeline during earthquake
(kgf/cm^2)

		Case 1 (El-Centro wave)	Case 2 (Hachinohe wave)
Axial stress	Tension	297.90	321.80
	Compression	−276.50	−335.70
Horizontal shearing stress		−5.29	10.64
Vertical shearing stress		18.69	36.37
Horizontal bending stress		625.90	1 075.00
Vertical bending stress		−322.20	−471.40

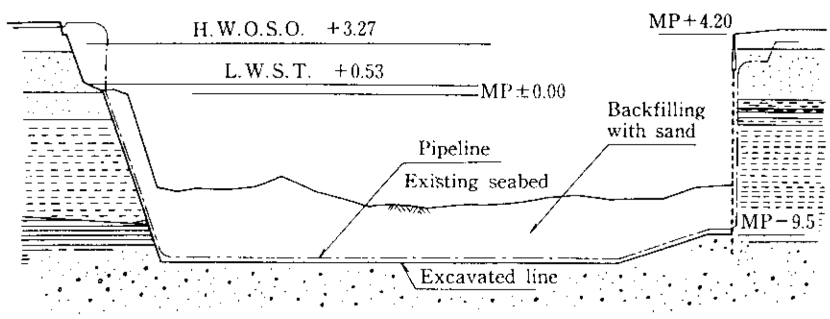

Fig. 6 Ground model

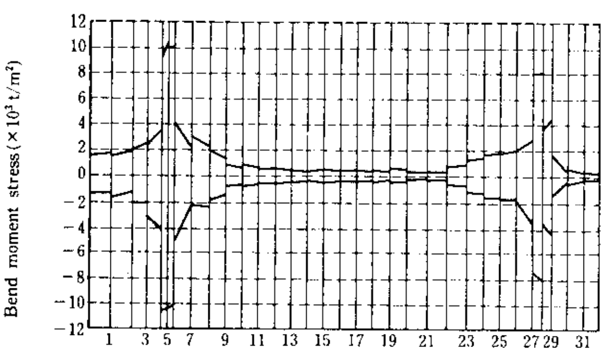

Fig. 7 Example of output of dynamic analysis of submarine pipeline

these data, both stresses and displacements are large where the environments around the pipes change. This result is characteristic of the response analysis.

Each stress shows the following features:

(1) Axial stress has peaks near the riser parts.
(2) Shearing stress has peaks at the piping bridges.
(3) Bending stress has peaks near the bent parts of the sunken pipeline.

These stresses are all within the allowable limits; therefore, there is no problem.

4 Dredging Work

There were various constraints on the dredging work because it was most important to carry out the work without impairing the port functions. The constraints and the countermeasures are as follows:

(1) It was necessary to carry out the work without stopping the navigation of ships. Therefore, the route was divided into three parts, with each work area 70 m long and 60 m wide. The dredger was fixed by spuds because the anchor goes out from the work area when fixed by anchor.

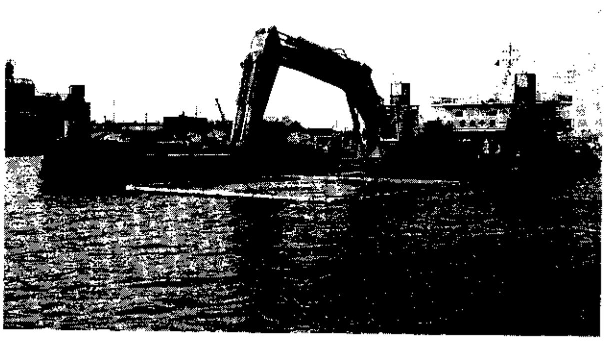

Photo 2 Backhoe dredger

(2) Because of the short work period, a high work efficiency was required. A large backhoe dredger (**Photo 2**) equipped with 4.6 m^3 bucket was adopted to increase the dredging efficiency, and the quality control was performed in high work accuracy as described below to eliminate the need of reworking.
(3) When hard sandy soil with N value higher than 50 was to be excavated, 3m^3 ripper bucket was provided to the above backhoe dredger.
(4) Because of the deep excavation, the arm of the backhoe was reformed into a long one.
(5) High work accuracy (+100 mm, −200 mm) was required. The microcomputer control system mounted on the backhoe dredger was used most effeciently and the measurements was carried out in an elaborate manner.

Since there was fear of troubles with third parties, posters were delivered beforehand and safety provisions, for example, large guardships, were sufficiently provided.

5 Civil Work for Riser Pipe at Tokyo Steel

5.1 Structure

For safety, the riser pipe at Tokyo Steel was required to be installed inside of the quay wall. Therefore, a part of the existing steel sheet pile quay wall was disassembled for this work. Since the quay was in use, there were various constraints involving work period, work area, and existing quay walls, so the determination of work method and structure was made using sufficient study, including a making of models.

Several work methods and structures were compared,

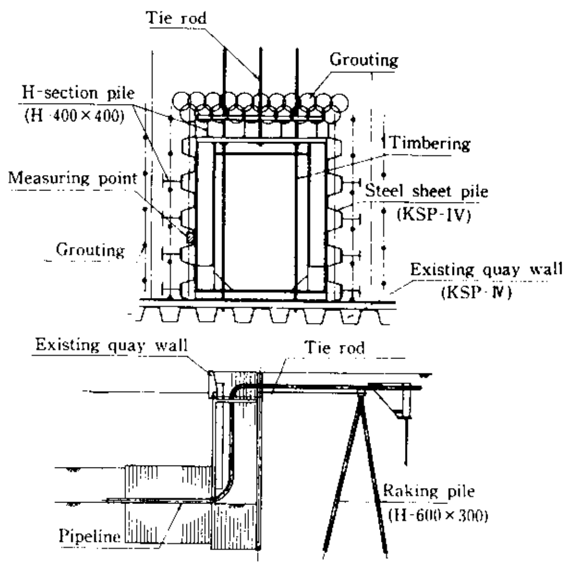

Fig. 8 Structure of temporary retaining wall

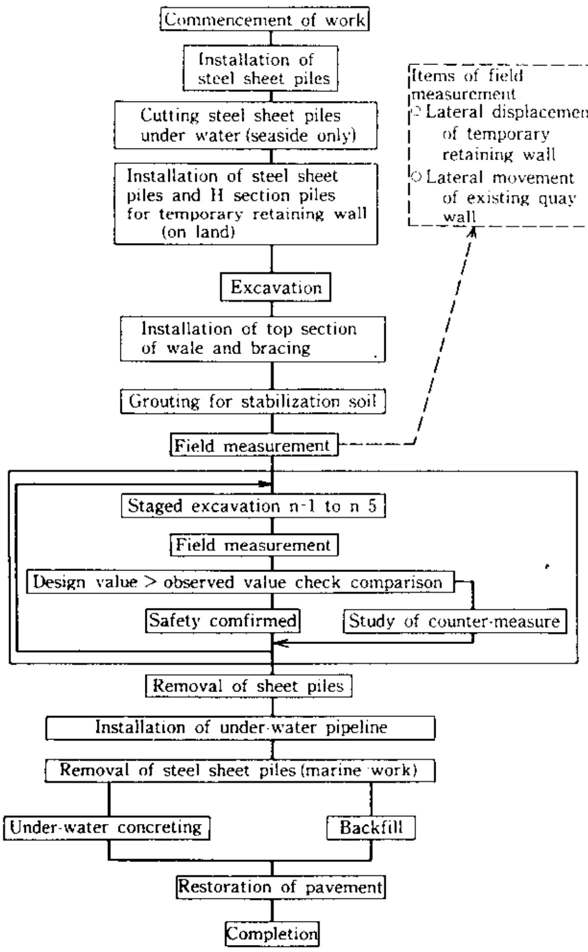

Fig. 9 Flow diagram of civil work at existing quay

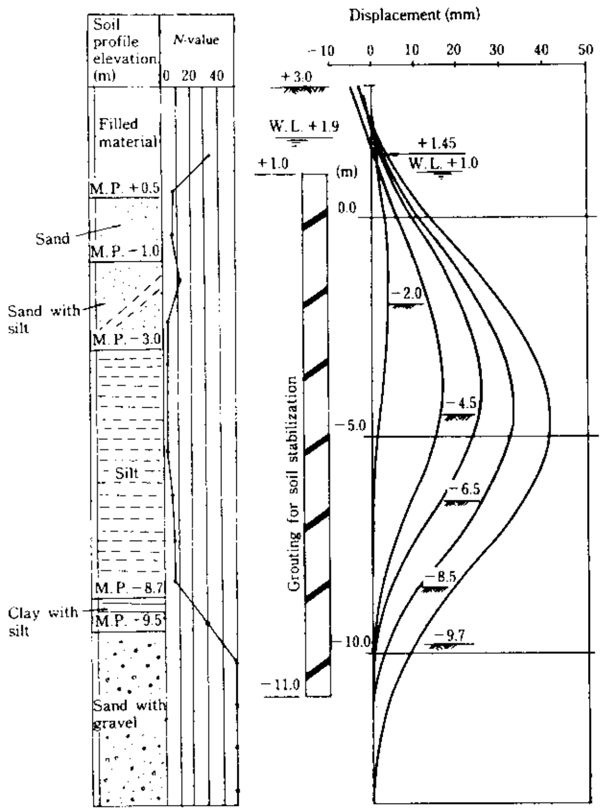

Fig. 10 Horizontal displacement of landslide protection wall

and the simplest structure with the least excavated earth was adopted. **Figure 8** shows this structure. The earth pressure in the land side of the excavated part of the quay is supported by the H-section piles and the reinforcing grouting and raking piles provided at the back of the grouting. The earth pressures from both sides are supported by the H-section and steel sheet piles which are combined together by the grouting. The waling and struts must be removed when the pipes are sunk and the mounting work must be carried out in water. For these reasons, only one set of waling and struts were constructed at the upper part, though deep excavation was performed. In operation, site measurement was carried out to grasp the current conditions, and the results were immediately fed back to the operation to progress the work with the safety of the construction confirmed. **Figure 9** shows the flow diagram of the work.

5.2 Control by Site Measurement

5.2.1 Behavior of sides of excavated part

The lateral movement of the land-slide protection walls was measured by slide type continuous inclination gages which are highly reliable and can indicate continuous behavior. To avoid the influence of the tide, the measurement was carried out at the same level of the tide. The results are shown in **Fig. 10**. The maximum point of the displacement of the land-slide protection walls shift to a deeper position when the excavation advances.

When the excavation work was finished, the maximum displacement was 42 mm, and the maximum stresses in the H-section and steel sheet piles were 1540 kgf/cm^2 and 1300 kfg/cm^2, respectively, which are within allowable limits. The latter two values were calculated using the result of displacement.

5.2.2 Behavior of existing quay wall

The behavior of the existing quay wall was obtained by measuring the displacement of the quay wall head using the inclination gages, described above, and transits. The head was moved to the sea side by up to 9 mm, which is not a serious value.

6 Fabrication, Towing, and Sinking of Long Pipe

6.1 Fabrication of Long Pipe

The long pipe was fabricated at the temporary yard in Mizushima Works of Kawasaki Steel, and towed into the inner area of Mizushima Port, then sunk.

Since the pipeline has a double-wall structure, it was fabricated in five blocks as shown in **Fig. 11**. The inner pipe must withstand high-pressure oxygen gas; therefore, it was necessary to inspect all the weld zones visually for high-pressure gas leakage. For this reason, only the inner pipes were welded together and inspected for each block, and then the produced long pipe was covered by outer pipes. In connecting two blocks together, the inner pipes were welded first, and then the weld zone was inspected. Then, to make outer pipe, the weld zone was covered with two pieces of a half-divided pipe, and these pieces were seam-welded into a'pipe which serves as jacket. Since the pipeline transports oxygen, special attention was paid in removing impurities, oil and grease.

6.2 Launching and Towing

To make lighter the in-water weights, floaters were attached to the pipeline. Two riser parts of the pipeline were hooked up by 50-t and 70-t floating cranes, and the middle horizontal part was hooked up by eight truck cranes, then the pipeline was suspended. The pipeline was moved vertically or horizontally by 50 cm at a time till it went above the sea and landed on water. In this operation, the condition of the pipeline was carefully inspected. Then, the pipeline was transferred by about 100 m off the coast, and the riser parts were made to be in the vertical position, in which condition the pipeline was moored for a night. The next day, the pipeline was towed at 2 knots along the east coast of Mizushima Port to the sinking site and temporarily moored. In this operation, the pipeline was guarded by two 2 600 PS class tugboats at its front and back, and by small ships on both sides.

6.3 Sinking

For one riser part of the pipeline, two truck cranes, 45 t and 36 t, were arranged on the quay wall and, for the other riser part, a 50-t floating crane was positioned. After the last ferryboat passed, following the complete navigation prohibition announcement by the Port

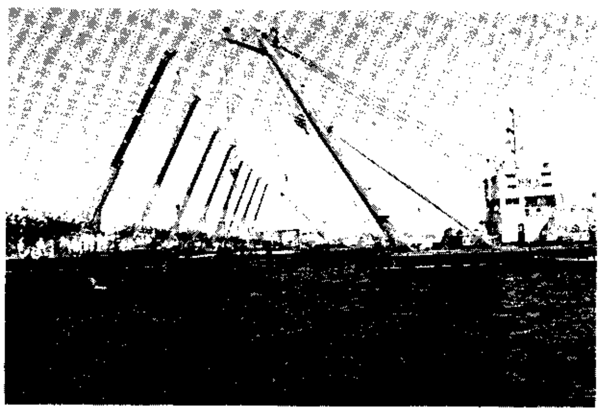

Photo 3 Launching

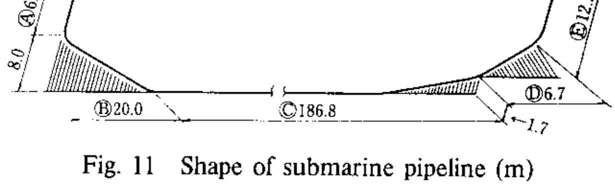

Fig. 11 Shape of submarine pipeline (m)

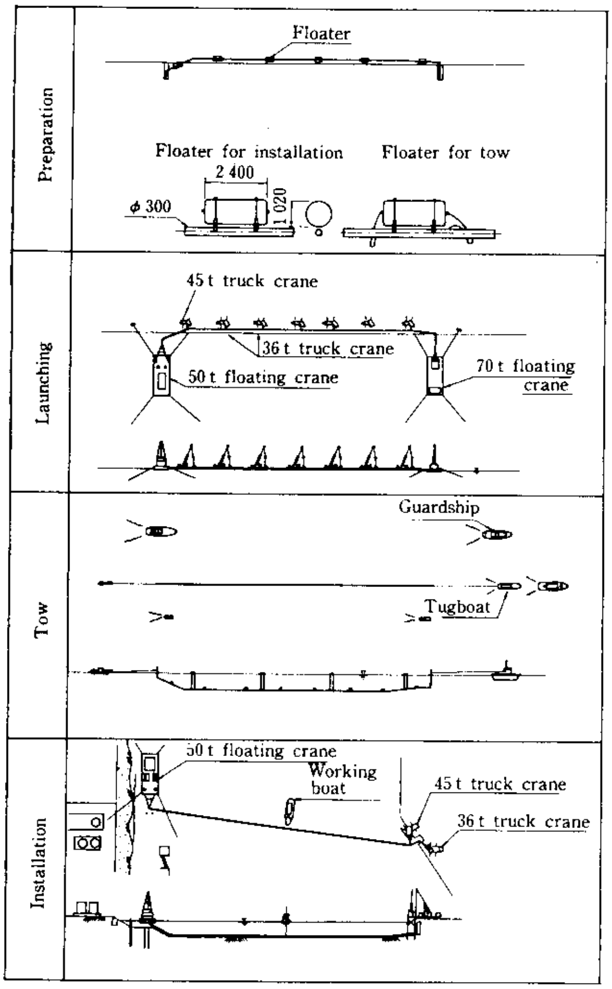

Fig. 12 Outline drawing of installation work

Chief, the pipeline sinking operation was started. **Photo 3** and **Fig. 12** shows operation conditions and **Fig. 13** indicates the flow diagram of the sinking work. The operation was progressed on schedule and completed with no trouble.

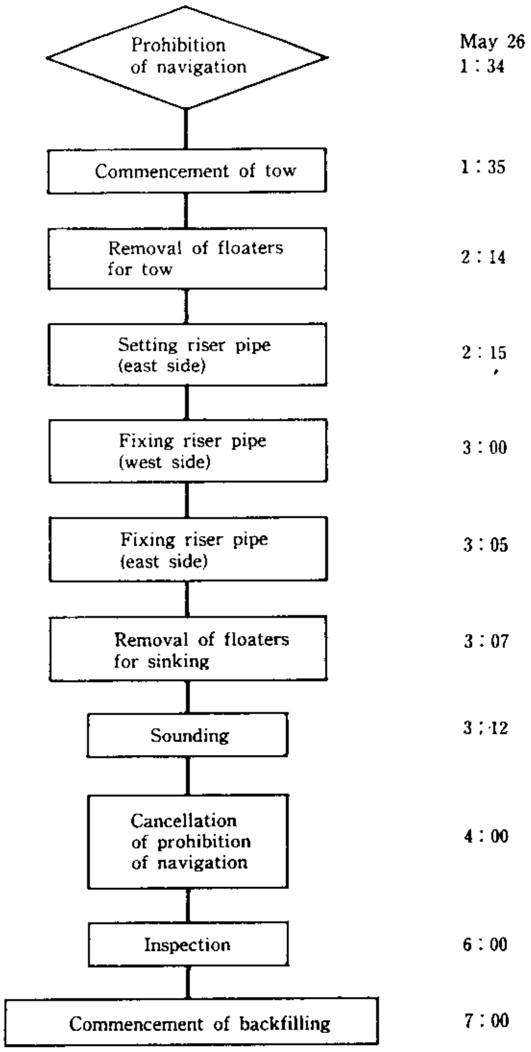

Fig. 13 Flow diagram of sinking work

7 Conclusions

A submarine pipeline was installed at Mizushima Port by the floating tow method. The features of this work are as follows:

(1) To excavate hard seabed within a limited work area, a large backhoe dredger fixed with spuds was used.
(2) A complex shape double wall pipeline was fabricated on land and sunk by floating tow method.
(3) Since the excavation work at Tokyo Steel side had to be carried out deep in water, sufficient measuring control was performed during the work.
(4) Since the work had to be carried out within the inner area of Mizushima Port where many ships navigate, a special attention was paid to announcements to the persons concerned, and to safety provisions such as arrangement of guardships.

Finally, the authors acknowledge the government offices and enterprises concerned including the builder, Osaka Oxygen Kogyo Ltd. Without their guidance and cooperation, this substantially difficult work could not have been completed.

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