Application of Extra-High Tensile Strength Steel for Hydropower Plants in Japan

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Abstract

High tensile steel has been utilized from the viewpoint of economy as penstocks came to have a larger water head. As for penstocks in Japan, hydraulic plants started operations using HT570 in 1960, HT780 in 1975 and HT950 in 2005. In the process of practical application, technical development has been promoted in fields such as steel materials, welding consumables, fabrication, installation and inspection. Scholars, electric companies, fabricators and material manufacturers have jointly continued development and verification for the practical application of high tensile steel by accumulating new technologies based on traditional philosophies. This paper will introduce the technologies and philosophies of high tensile steel materials, welding consumables, welding procedures, the performance of base materials and weld joints, and inspections concerning all of the above.

1. Introduction

1.1 Merits of high tensile steel

From the viewpoint of merits of scale, hydraulic plants have tried to attain higher water head and larger capacities. The internal design pressure of penstocks becomes larger accordingly, and the steel pipe becomes thicker, thus increasing the weight and welding amount. In these situations, reducing the thickness can reduce the weight and welding amount of steel pipes, and the construction cost can therefore also be reduced. Table 1 shows the steel materials and the relations among the plate thickness, weight and welding amount. Since the weight of steel pipe is proportional to plate thickness, and the welding amount is generally proportional to squared plate thickness, it is known that the application of high tensile steel greatly affects work performance, construction time and cost.

1.2 Larger penstocks and high tensile steel

For the first time in Japan, Morozuka Power Plant, completed in 1960, employed HT570 (max thickness: 20 mm). In 1963, HT730 of plate thickness 30 mm was utilized in Kinugawa Power Plant, and in 1972, HT680 of max plate thickness 34 mm was utilized in Numahara Power Plant. In 1975, HT780 of max plate thickness 34 mm was utilized in Ohira Power Plant for the first time, and the penstocks using HT780 were constructed thereafter. The penstock became larger, and high tensile steel was utilized as shown in Fig. 1. At Kazunogawa Power Plant, having the greatest scale of all, the max plate thickness reached 94 mm by using HT780.

Also, in the export of penstock parts and bifurcation and the steel materials used for penstocks, a number of achievements can be noted. In larger scale penstocks, materials and parts were supplied to BAJINA BASTA (former Yugoslavia) in 1975, CHAIRA (Bulgaria) in 1981, and to GUAVIO in 1989. At SAMANALAWEWA (Sri Lanka), PURULLIA (India) and NAM THUEN-2 (Laos), installation work was also carried out.

TABLE 1: Effect of high tensile steel application

<table>
<thead>
<tr>
<th>Strength of steel material</th>
<th>Plate thickness</th>
<th>Weight ratio (%)</th>
<th>Welding amount ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild Steel (400N/mm² class)</td>
<td>(mm) 90</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>HT570 (570N/mm² class)</td>
<td>45</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>HT680 (700N/mm² class)</td>
<td>36</td>
<td>40</td>
<td>16</td>
</tr>
<tr>
<td>HT780 (780N/mm² class)</td>
<td>33</td>
<td>37</td>
<td>13</td>
</tr>
<tr>
<td>HT950 (970N/mm² class)</td>
<td>27</td>
<td>30</td>
<td>9</td>
</tr>
</tbody>
</table>

Fig. 1: Changes of penstock scale & steel materials utilized
2. Development of High Tensile Steel Materials

2.1 Development of HT950

As penstocks become larger, it is necessary to apply materials of higher strength. Since around 1982 electric power companies and fabricators started to develop and study HT950 steel materials welding consumables and welding procedures. Based on the results of these researches, the Japan Hydraulic Gate & Penstock Association established “Technical Guidelines for 950N/mm² class high tensile steel material (HT100) utilized to penstocks” in 1999, which was approved at the same time as the standard of the Japan Electrotechnical Standards and Codes Committee (JESC).

For the first time in Japan, HT950 was utilized in Kannagawa Power Plant (Tokyo Electric Power Co., Inc.), starting operations in 2005. The maximum plate thickness was 94 mm, and about 2,330 tons of HT950 was used for the 1st-term construction (approx 46% of steel pipe in weight). About 1,600 tons of HT950 (approx 37% of steel pipe in weight) was further utilized in the 1st-term construction of Omarugawa Power Plant (Kyushu Electric Power Co., Inc.). The maximum plate thickness was 70 mm. Kannagawa Power Plant and Omarugawa Power Plant are the only plants in the world using HT950 in penstocks. These penstocks are outlined in Figs. 2 and 3, while the materials used are shown in Fig. 4. At Kannagawa Power Plant, about 17% of materials by weight were saved by using HT950, and the time needed for installing the inclined shaft was reduced by about 10% compared to using steel material up to HT780.

2.2 Manufacturing process of high tensile steel

In HT780, the steel plate manufacturing process has been rationalized by converting from the ingot making method (ingots) to the continuous casting method (CC). In HT570 or lower grade, welding without preheating is put to practical use by adopting TMCP (Thermo-Mechanical Control Process) and low P\textsubscript{CM} (Note 1). This enables reduced welding procedure control, and reduces costs as well as stabilizing the quality. HT950 was mainly produced by continuous casting and special TMCP was utilized.

2.3 Materials for bifurcation

In recent years, the main type of bifurcation utilized has been internal reinforcement. The thickness of the sickle plate (crescent reinforcing parts reinforcing the cross line between branch from main pipe) is also thicker as the penstock becomes larger. Since sickle plate is extremely thick and stress works in the plate thickness direction, the HT780 Z plate has been developed and plate of 135 mm thickness was delivered to BAJINA BASTA Power Plant. Also, for the CHAIRIA Power Plant, a Japanese fabricator delivered a bifurcation using HT780 Z plate of 180 mm in thickness in 1984.

*(Note 1) P\textsubscript{CM} = Crack sensitivity composition
P\textsubscript{CM} = C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B*

Fig. 2: Overview of Kannagawa Power Plant penstock (Tokyo Electric Power Company)

Fig. 3: Overview of Omarugawa Power Plant penstock (Kyushu Electric Power Company)

Fig. 4: Configuration of materials utilized

At Oku Mino Power Plant, completed in 1993, a HT780 Z plate of 175 mm thickness was used. For Kazunogawa Power Plant, a sickle plate that was partly structured by reinforcing both sides of 160 mm with 60 mm plates (total thickness: 280 mm) was used. At Kannagawa Power Plant, HT950 was used for the shell of bifurcation. However, a HT780 Z plate of 200 mm was used for the sickle plate. Fig. 5 shows bifurcation for Kannagawa Power Plant.

To manufacture Z plate, special ingot making methods called...
“unidirectionally solidified ingot” method (Fig. 6) were used to secure the quality of extreme thick materials. Recently, because of improved purity of steel materials, a normal ingot making method is often used. At Omarugawa Power Plant, HT950 Z plate manufactured by a special continuous casting method was used for the first time. This sickle plate is partly structured by reinforcing both sides of a 70 mm Z plate with 65 mm plates (total thickness: 200 mm). Fig. 7 shows bifurcation and the sickle plate used at Omarugawa Power Plant.

Fig. 5: Kannagawa Power Plant, 2nd bifurcation

Fig. 6: Unidirectionally solidified ingot method [15]

Fig. 7: Omarugawa Power Plant bifurcation, Sickle & temporary assembly

2.4 Welding Consumables & Welding Procedure

Development of welding consumables for high tensile steel has kept pace with the development of steel materials. By 1958, the SMAW materials of HT570 and HT780 were developed, and by 1960, SAW and MAG welding consumables for HT570 and HT780 were developed. Welding materials for HT950 were developed by 1990.

1) Development of welding consumables for HT780 steel

In the development of welding consumables for HT780, (a) improvement of cold crack resistance and (b) greater toughness were the main accomplishments.

(a) Improvement of cold crack resistance

In the improvement of cold crack resistance, various researches were carried out to prevent the cold cracks caused by hardened HAZ and/or diffusible hydrogen. The welding crack sensitivity of steel materials was successfully improved mainly by lowering $P_{CM}$. For welding consumables, examinations were carried out on the effects by strength level, deposit thickness and amount of diffusible hydrogen, and it was determined that the preheating temperature required to prevent cold cracks can be lowered as the amount of diffusible hydrogen is smaller and strength is lower. Fig. 8 shows the data for the restrained multi-layer SAW crack test where the relations among the amount of diffusible hydrogen, strength and preheating temperature to prevent cold cracks are shown. Here, it is clearly illustrated how these factors affect the crack resistance.

On the welding consumables of low hydrogen, researches were actively started in the 1970s when crack-free steel was developed. SMAW materials of extra low hydrogen, a moisture resistant type, and the bond flux for SAW were developed. Cold crack resistance of the welding consumables for high tensile steel has also been improved by applying this concept.

At Hongawa Power Plant, completed in 1982, the concept of “Soft joint” was used for the first time, which utilized the 600 MPa class welding consumables to the circumferential welding of the HT780 penstock, for the purpose of reducing the risk of cold crack in field welding of high temperature and high humidity conditions. This concept is utilized as a method to reduce the risk of cold crack in high tensile steel, such as in the tack welding, 1 ~ 2 pass welding in the groove start and repair welding.

(b) Higher toughness

Improvement of toughness of weld metal used to be one of the biggest issues. In weld metal up to HT570, toughness was increased by a complex addition of Ti and B. In the weld metal of HT780, however, toughness was improved by miniaturizing the microstructure using Ni.

Fig. 8: SAW’s restraint multi-layer welding crack test [12]
2) Development of HT950 welding consumables
For the HT950 welding consumables, it was requested that welding be carried out in similar conditions to HT780. So, the requirement of the preheating temperature, inter-pass temperature and welding heat input were the same as that of HT780. In toughness, similar to HT780, the stipulation that “Brittle fracture must not initiate from weld metal at the minimum operating temperature (0°C)” was requested. The most important point in the development of welding consumables was the improvement of welding toughness of metals and crack resistance to secure the workability of welding.

(a) Higher toughness
In the approach toward improved toughness of the weld metal, the important issues were the miniaturization of microstructure by reducing the amount of oxygen and the improvement of ductile crack resistance. The amount of oxygen is basically reduced by effectively promoting a chemical reaction (deoxidization) in welding. In SMAW and SAW, oxygen was minimized by utilizing a strong deoxidizing agent.
In MAG welding Ar + 5 ~ 10% CO₂ sealed gas was utilized and the acidity of the arc atmosphere was reduced. Also by utilizing strong deoxidizing components, oxygen was minimized. The amount of oxygen in welding metals was reduced thereby from the conventional 300 ~ 1000 ppm to 150 ~ 200 ppm or so. Fig. 9 shows the influence of oxygen content on notch toughness. Adding appropriate amounts of Ni also increased toughness.

Fig. 9: Influence of oxygen content in weld metals on notch toughness (SMAW) [12]

(b) Improvement of cold crack resistance
As shown in Fig. 8, weld metal becomes more sensitive to hydrogen embrittlement as the strength increases. In the presence of a small amount of hydrogen, cold cracks often occur in the welding metals or HAZ. To improve the cold crack resistance of HT950 weld metal, it is effective to suppress the strength of weld metal in the allowable range and reduce the hydrogen source as far as possible.
In order to meet the requirement that “HT950 welding be carried out by similar welding conditions as HT780” it is necessary to realize a similar performance of weld metal cold crack resistance between HT780 & HT950. To secure cold crack resistance, therefore, it is essential to further reduce the amount of hydrogen.
Concerning the hydrogen source in weld metal, hydrogen intrudes through welding consumables in MAG, TIG and SAW, and mostly intrudes from the atmosphere in SMAW.
In the flux in SMAW and SAW, the amount of hydrogen in welding metals was reduced by examining the raw materials and baking requirements. In the MAG and TIG wires, the surface properties of wires were improved. As a result, the cold crack prevention preheating temperature of MAG and TIG became 50°C or lower. In SMAW and SAW, it was ensured that cold cracks could be prevented at a preheating temperature of 100°C or lower on the precondition of co-using post heating immediately after welding.
The preventive preheating temperature of HAZ was mostly evaluated by y-groove weld cracking test (JIS Z 3158) for HT780. In the case of HT950, however, the crack characteristics of weld metal itself plays the main role. For the method of testing cracks, a u-groove weld cracking test (JIS Z 3157) to determine the crack preventive preheating temperature of weld metal was carried out in addition to the y-groove weld cracking test. Similar to the case of HT780, an additional multi-layer welding crack test was carried out, and the preheating/post-heating conditions required to prevent welding cracks were thereby determined.
HT950 weld joints were made with similar welding conditions to HT780 and various tests on the strength/fracture toughness of joints were carried out. All requirements were met, including the request for toughness that welds should not initiate brittle fracture at minimum operating temperature (0°C).
In the development of welding consumables, as shown here, emphasis used to be put on how to realize cold crack resistance performance and higher toughness. Development work went on under the concept that the strength of welding metal should be designed to be the lower limit value, by which the strength of the weld joint can be secured in combination with the base material.

3. Properties of Base Material and Welded Joint
Features of required specifications of HT780 and HT950 utilized in penstocks are outstanding in demands for greater toughness and superior welding performance. Table 2 shows the required values for the design standard strength, base metal and welded joint, and Table 3 shows actual chemical components of the HT950 steel plate compared with the standards.
According to the facts allowable stress is suppressed to a low level, and required values for base metal impact performance are rather high. High toughness and good crack resistance performance should be secured by suppressing C, Ceq and P_CM.
TABLE 2: Design standard and strength (t ≤ 50)

<table>
<thead>
<tr>
<th>Item</th>
<th>HT780</th>
<th>HT950</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base metal</td>
<td>685 ≤</td>
<td>885 ≤</td>
</tr>
<tr>
<td>Weld joint</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base metal</td>
<td>330</td>
<td>400</td>
</tr>
<tr>
<td>Weld joint</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile strength (N/mm²)</td>
<td>780 –</td>
<td>780 ≤</td>
</tr>
<tr>
<td></td>
<td>930</td>
<td>950 –</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1130</td>
</tr>
<tr>
<td>Allowable stress (N/mm²)</td>
<td>3050</td>
<td>3050</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3050</td>
</tr>
<tr>
<td>Safety factor for</td>
<td>2.35</td>
<td>2.35</td>
</tr>
<tr>
<td>tensile strength</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test temperature</td>
<td>-40°C</td>
<td>0°C</td>
</tr>
<tr>
<td>(required vTrs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charpy absorbed</td>
<td>47J ≤</td>
<td>47J ≤</td>
</tr>
<tr>
<td>energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brittle fracture</td>
<td>≤50%</td>
<td>≤50%</td>
</tr>
<tr>
<td>percent</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE 3: Chemical composition of base materials (t ≤ 50)[10]

<table>
<thead>
<tr>
<th>Item</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
<th>B</th>
<th>Ceq</th>
<th>Pcm</th>
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<tbody>
<tr>
<td>HT780</td>
<td>0.18</td>
<td>0.55</td>
<td>1.50</td>
<td>0.015</td>
<td>0.50</td>
<td>0.50</td>
<td>0.80</td>
<td>0.60</td>
<td>0.05</td>
<td>0.05</td>
<td>0.33</td>
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<td></td>
</tr>
<tr>
<td>HT950</td>
<td>0.14</td>
<td>0.11</td>
<td>0.50</td>
<td>0.015</td>
<td>0.50</td>
<td>0.50</td>
<td>0.80</td>
<td>0.60</td>
<td>0.05</td>
<td>0.05</td>
<td>0.33</td>
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<tr>
<td></td>
<td>0.09</td>
<td>0.09</td>
<td>0.74</td>
<td>0.003</td>
<td>0.0002</td>
<td>0.02</td>
<td>1.04</td>
<td>0.49</td>
<td>0.43</td>
<td>0.04</td>
<td>0.51</td>
<td>0.24</td>
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<tr>
<td>EN101137</td>
<td>0.20</td>
<td>0.5</td>
<td>1.68</td>
<td>0.007</td>
<td>0.0002</td>
<td>0.26</td>
<td>1.99</td>
<td>0.71</td>
<td>0.56</td>
<td>0.10</td>
<td>0.0010</td>
<td>0.57</td>
<td>0.27</td>
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</tr>
</tbody>
</table>

3.1 Toughness
The required specification for base metal is “Performance to stop propagation of brittle fracture at 0°C,” and the required specification for welded joint is “Performance not to initiate brittle fracture at 0°C.”

In order to ensure that these specifications are met, the base metal is verified to have the ability to stop propagation of brittle fracture at 0°C. The brittle fracture test is known as the ESSO test of temperature gradient type carried out by max plate thickness. In the delivery of material thereafter, performance is verified by converting this to the requirement for the Charpy impact test (requirement of fracture appearance transition temperature: vTrs). Charpy impact test shall be carried out at the temperature of vTrs required. Brittle fracture percent of fractured surface shall be less than 50%.

Concerning the welded joints, brittle fracture tests such as the CT test are carried out at the Bond to ensure that the performance not to initiate brittle fracture at 0°C is retained. As shown in Fig. 10 welded joints of K groove are produced, and notchcd at the Bond of the straight side groove.

In the welding procedure test, performance is verified by converting this into the requirement for the Charpy impact test (fracture appearance transition temperature: vTrs).

As described above, different specifications of toughness are requested for the base metal and the welded joint because it is technically impossible to produce welded joints at the same level as base metal.

3.2 Weldability
Steel materials and welding consumables are required to have good welding performance so that the welding work requirements such as preheating temperature, heat input and post-heating conditions may be at appropriate levels. In order to meet the standards of welding conditions as stated in Table 4, steel materials were required to set carbon equivalent (Ceq) and crack sensitivity composition (Pcm) to a low level. As for the welding consumables, strict requests are made for the diffusible hydrogen amount of welding metal. The strength of weld metals is set low. In the manufacture of HT950 steel, minor elements like Nb and V are utilized to realize such strict requirements. The latest steel-making technologies are also utilized by employing TMCP and special heat treatment methods and minimization of P and S.

TABLE 4: Welding conditions [10]

<table>
<thead>
<tr>
<th>Item</th>
<th>HT780</th>
<th>HT950</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preheating temp.</td>
<td>100°C or higher</td>
<td>100°C or higher</td>
</tr>
<tr>
<td>Inter-pass temp.</td>
<td>230°C or lower</td>
<td>230°C or lower</td>
</tr>
<tr>
<td>Heat input</td>
<td>45 KJ/cm or less (joint average)</td>
<td></td>
</tr>
<tr>
<td>Post-heating</td>
<td>Not required</td>
<td>150°C x 2 hr. or more</td>
</tr>
</tbody>
</table>

4. Fabricating Procedure
4.1 Unit Pipes
To install the steel pipes at a pumped storage power station, a site plant is constructed because of restrictions due to transportation. The unit pipes are fabricated there and carried into and installed in the tunnel.

Application of HT950 enables a reduction in the weight of the unit pipe, and an increase in the length of unit pipe. In the project applying HT950, the construction period was effectively reduced by increasing the length of the unit pipe from 12m to 15m. Fig. 11 shows the installation speed of the inclined shaft, where large blocks contribute to reduce the construction period.
4.2 Welding at Site Plant

At a site plant, unit pipes of 3m are fabricated by welding vertical joints for two shells, and five of them are connected to make a unit pipe of 15m. In this welding, SAW is utilized. By making long unit pipes, the welding amount increases at the site plant as compared with the welding in the tunnel, and the welding at the site plant is a critical process. This problem has been solved successfully by applying the system of simultaneously welding the four circumferential joints shown in Fig. 12. As the four submerge arc welding machines should start at the same time, a special power unit using high-frequency currents in arc start, so that arc may start while the work is rotating.

The preheating temperature of tack welding is controlled to be 25 °C or higher than the specified temperature to reduce risks of cold crack. Welding consumables of strength lower than the base metal are also utilized for the same purpose. In order to prevent welding defects including cracks in the root, back chipping is required. However, the groove shape should be unified after gouging because four circumferential weldings should be carried out simultaneously. This is why automatic plasma gouging was utilized. This method is easily automated, has a unified groove shape and produces lower amounts of noise and dust.

4.3 On-site Tunnel Welding

For on-site tunnel welding, an automatic welding system has been developed since around 1970 to improve welding quality, reduce the amount of labor required for welding and reduce the work time. The welding system initially utilized performs automatic welding from the interior, back chipping and shielded metal arc welding of 3 ~ 5 passes from the exterior.

The new welding system minimizes the work done on the exterior and most of the steel pipe installation work was carried out from inside the pipe. One-side automatic welding is utilized; so that concrete can be charged into parts completed one cycle before, during the welding process. Fig. 13 shows the groove shapes in several automatic welding systems developed by the companies.

Since gas shield arc welding is used, air-flow is shut off to prevent any wind going into the welding floor. Consequently, the temperature of the welding floor rises due to preheating and welding heat, and therefore, the automatic welding system is controlled remotely in the operating room on another floor to avoid ill effects to welders and electronic devices.

<table>
<thead>
<tr>
<th>Welding method</th>
<th>Automatic TIG welding</th>
<th>Automatic MAG welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backing material</td>
<td>Glass wool</td>
<td>Glass wool</td>
</tr>
</tbody>
</table>

**Fig. 13: Comparison of grooves of one-side welding**

4.4 One-side Welding

A one-sided welding method using backing metal and a special backing plate named BAU is also used in addition to ordinary backing metal. BAU is devised to allow for larger allowable values of installation error as shown in Fig. 14. Welding using backing metal is utilized up to the HT570 class. For class HT780, backing metal is not utilized to avoid the risk of welding cracks or of welding defects possibly remained in the root. Grout holes are not bored into high tensile steel for similar reasons.

Therefore, the one-sided welding utilized with high tensile steel is called the “uranami” method, which forms exterior weld reinforcement (uranami) from the interior. In order to form outside reinforcement efficiently, glass wool or ceramic backing materials which are removable are used as shown Fig. 13.
4.5 Automatic Welding Method utilized in HT950

A one-sided automatic welding system utilized to HT950 penstocks will be introduced. Application of one-sided welding made it possible to perform the concrete casting of exterior unit pipe that was completed one cycle before, simultaneously with welding work. As compared with conventional work, the one cycle period was thereby reduced to 10 days from 16 days, as shown in Fig. 15.

Fig. 16 shows the system configuration, Fig. 17 shows the welding system, Fig. 18 shows the backing equipment, Fig. 19 shows the remote control unit, and Fig. 20 shows the cross section of the weld.

The welding unit runs on the rack pinion rails installed in the work unit provided in the pipe. Two welding units are provided per seam, and welding floors are so designed so as to work two seams at the same time. The welding head is equipped with a 3D oscillator, forward/backward/right/left torch angle adjustment mechanism, arc monitor camera and groove profiling sensors. In order to realize one-sided welding by MAG welding at all positions, backing equipment has been developed, by which glass wool backing is automatically attached and removed. This equipment runs in synchronization with the internal welding unit, on the angle rails installed out of the pipe. This equipment presses the glass wool backing material with a copper plate. After welding, the backing material is peeled off and wound up on the reel.

The welding control unit is installed in the operation room on top of the work unit, to remotely control the four welding units in two seams and the backing equipment. Welding conditions are controlled by automatically selecting the optimum conditions in each welding position that are previously collected in the database. An operator fine-tunes the conditions while checking the arc monitor and penetration bead monitor.

5. Inspections

5.1 Nondestructive Test Methods

For the nondestructive test of butt welding joints, radiography or ultrasonic tests should be carried out. Radiography was usually used for butt joints, and for the T joints of bifurcation, ultrasonic tests were used. Lately, however, an automatic ultrasonic test is occasionally used for the butt joints.

5.2 Automatic Ultrasonic Test

Fig. 21 shows the automatic ultrasonic test equipment used.
This is to find faults simultaneously from both sides of the weld, and two different refracting angle probes are assembled on one side. It is possible, therefore, to find flaws in two refracting angles in one run from both sides of the weld. The operating procedure is to move in a 3mm pitch in square, and in case any flaw echo is sensed, flaws are detected precisely in 0.5mm pitch by moving back one pitch. Additionally, the inspection results are judged automatically.

Additionally, it was another important point, we believe, that actions of material manufacturers and fabricators have been taken based not on the policy of “Meeting a few request specifications described in the contract” but on the policy of “Manufacture only after understanding the background to determine the specifications” in execution of work.

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6. Summary

In Japan, operation of the first penstock using HT570 was started in 1960, and a penstock using HT780 was completed 15 years later. Operation of penstocks using HT950 was started 45 years later in 2005.

At stages in the history of the practical use of high tensile steel, scholars, electric companies, fabricators and material manufacturers have jointly set, developed and verified the performance requirements while paying appropriate attention to “(Ease of application) for execution control with margin” against contradictory requirements, of “Ease to manufacture steel materials and welding consumables”. Such achievements are standardized, and the standards reflecting the experiences of utilization have been revised continuously. The history of such examinations may be one of the features in the development and practical application of high tensile steel in Japan.

It can be said that high tensile steel has played an extremely important role in the improvement of large-scale penstocks and reducing construction costs. Bases supporting such improvements are the development of steel making technology, welding consumable, automating technology and nondestructive test technology, joint researches by scholars, electric companies, fabricators and material manufacturers, and the standardization of such achievements.

**Fig. 21: Automatic ultrasonic test equipment**

**Fig. 22: Welding appearance inspection/repair equipment**