Development of 22-kV XLPE Cable and Joint with Reduced Insulation Thickness Having Water-Impervious Aluminum Layer

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ABSTRACT Electric power supply using 22-kV systems is expanding aiming at reduction of electric power distribution costs through upgrading the efficiency of facilities. It was thus required to develop a cable with joint that enabled maintaining the reliability as well as suppressing the cost of electric power supply. In response to this requirement, the authors have developed a new cable having a water-impervious layer of aluminum laminated tape together with its joint, whereby the thickness of the insulating layer was reduced to 4.5 mm --including the inner semiconductive layer-- by devising a novel method of terminating the end of the outer semi-conductive layer. Moreover, a cold shrinkable straight joint has been developed thus improving the working efficiency at the site. This paper reports on the structure, performance, and working efficiency of this cable and the joint.

1. INTRODUCTION

Electric power supply using 22-kV systems is expanding aiming at reduction of electric power distribution costs through upgrading the efficiency of facilities. In response to the requirement of developing a cable with joint that enables suppressing the cost while maintaining the reliability of electric power supply, we have developed a new cable with reduced insulation thickness having a water-impervious layer together with its joint.

By using an aluminum laminated tape for the cable and joint, we have been successful in maintaining the reliability while reducing the insulation thickness. This paper reports on the structure, characteristics, and working efficiency of this cable and the joint.

2. DESIGN OF 22-KV CV CABLE WITH REDUCED INSULATION THICKNESS HAVING WATER-IMPERVIOUS LAYER

2.1 Target Characteristics and Structure

Table 1 shows target characteristics. Whereas the electric characteristics are in compliance with JEC-3408-1997 [1], the lightning impulse test voltage is ±135 kV since lightning impulse withstand voltage (LIWV) is given as 95 kV.

As for the water-imperviousness of the cable, it was fixed at a value equivalent to that of water-impervious lead layer (WILL) having an established track record in the 66-kV CV cables currently in use.

2.2 Design Details

2.2.1 Investigation of insulation thickness

The cable insulation thickness was determined by adopting the greatest among those obtained by the electric field intensity of cable design (E_L) as well as the characteristics at the rise-up portion of the stress cone for joint and partial discharge characteristics. Required insulation thicknesses based the design factors mentioned above are described below.

(1) Insulation thickness based on the cable design

The insulation thickness based on the required AC withstand voltage is 2.3 mm including inner semiconductive layer (ISCL), given the AC design voltage of 35 kV/mm [2].

Table 1 Target characteristics of cable

Item	Target characteristics
Partial discharge	5 pC or less at 30 kV·10 min
AC withstand voltage	45 kV·1 hr
Lightning impulse voltage	±135 kV·3 repetitions (LIWV = 95 kV)
Long-term loading (in air)	20 kV loading; Conductor temperature: 90°C 8 hr ON / 16 hr OFF, 180 repetitions
Water imperviousness	Averaged water permeation: 1 x 10^{-7} g·(cm/cm^2)·day·mmHg or less

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Meanwhile, the thickness based on the required lightning withstand voltage is 2.8 mm including ISCL, given the lightning withstand design voltage of 75 kV/mm [2]. Thus, the insulation thickness based on the cable design was determined as 3.0 mm.

(2) Insulation thickness based on the characteristics at the rise-up portion of the stress cone for joint

Since reduction of the cable insulator thickness increases the electric field intensity on the cable insulator, withstand voltage characteristics of the rise-up portion of the stress relief cone must be considered. We calculated these characteristics based on the minimum breakdown voltage denoted by $G_{\min}$ that was derived from breakdown test data of joints.

Table 2 shows typical breakdown test data of 22-kV joints together with the calculated results, indicating that the cable insulation thickness can be reduced down to 4.0~4.5 mm including ISCL.

(3) Insulation thickness based on partial discharge characteristics at the edge of outer semiconductive layer

Since reduction of the cable insulator thickness has an influence on partial discharge characteristics at the edge of the outer semiconductive layer (OSCL), various termination methods were studied for their partial discharge characteristics. As a result, an insulation thickness of 4.0 mm including ISCL was identified to result in a partial discharge start voltage of 18.2 kV even for the greatest conductor size of 500 mm², thus meeting the specification for the joints of 17 kV•10 pC or less.

Taking into consideration, however, such variations as data spread and possible degradation due to working environment at the site, the insulation thickness should be 4.5 mm or more.

Based on the results of the foregoing investigation it was decided to adopt the greatest value of 4.5 mm including ISCL for the cable insulation thickness.

Table 2 Breakdown test data of joint

Joint type	Minimum breakdown voltage (kV)	$G_{\min}$ (kV/mm)	Insulation thickness including ISCL (mm)
Slip-on straight joint	AC 130	17.4	4.1
	Imp 380 *	51.0	4.2
Prefabricated joint	AC 167	19.8	3.7
	Imp 380 *	45.1	4.5

Notes
(1) The * mark corresponds to the data outside the rise-up portion of stress relief cone.
(2) Insulation thickness is calculated assuming that the required withstand voltage equals to the standard value multiplied by a sufficient margin --because of small numbers of measured data-- of 1.3.
AC: 45 kV x 1.3 = 58.5 kV
Imp: 135 kV x 1.3 = 175.5 kV

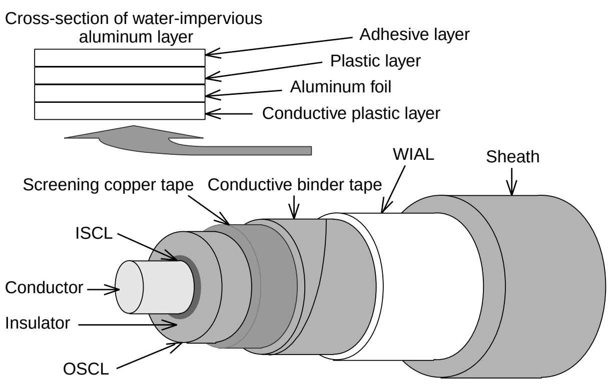


Figure 1 22-kV CVT cable with WIAL

2.2.2 Water-Impervious Layer

The water-impervious layer uses aluminum and employs a double laminated structure considering mechanical strength and corrosion resistance. The layer is placed underneath the cable sheath lengthwise and they are bonded together so as to improve the mechanical characteristics of the cable allowing them to integrally follow bending, expansion, and contraction of the cable.

2.2.3 Detailed Structure of the Cable

Figure 1 shows the structure of the CVT cable with water-impervious aluminum layer (WIAL) developed at this time.

3. CABLE EVALUATION

3.1 Initial and Long-Term Characteristics

Table 3 shows the results of the initial and long-term electrical characteristics tests of the developed cable. All test items are seen to meet the target characteristics.

Long-term loading tests of 180-day duration were carried out to confirm the long-term performance of the cable. As for the test conditions, not only in-air test conditions but also in-water test conditions were investigated simulating submerged conditions to be encountered in practical

Table 3 Electrical test results of 325-sq cable

Test item		Test results
Partial discharge test		No occurrence (30 kV·10 min)
Lightning impulse withstand voltage		±135 kV·3 repetitions: Good
Lightning impulse breakdown		-650 kV·1 repetition
AC long-term withstand voltage		45 kV·1 hr: Good
AC breakdown		325 kV·6 min
Long-term loading test (in air and in hot water)		No abnormalities
Residual performance after long-term loading test	Partial discharge test	No occurrence (more than 30 kV)
	AC breakdown *1	In air: 115~165 kV *2 In hot water: 135~145 kV *2
	Lightning impulse breakdown *1	In air: -345 kV *2 In hot water: -345 kV *2

Notes
*1: 60°C hot water long-term tests were carried out at the Central Research Institute of Electric Power Industry.
*2: All breakdowns occurred at joints.

installation environments. But if the water temperature was set to a normal temperature while raising the in-water cable conductor temperature to 90°C, the temperature of the in-air cable conductor --the test system is controlled based on this temperature-- would exceed the allowable temperature of the cable. Thus, the water temperature was set to 60°C enabling the test temperature of 90°C to be applied for both the in-air and in-water cables.

No abnormalities such as breakdown were found during this test. Furthermore, residual performance tests including AC partial discharge test, AC breakdown test, and lightning impulse breakdown test were carried out after this test, and it was confirmed, as shown in Table 3, that the performance remained unchanged from the initial characteristics.

3.2 Water-Imperviousness

The following tests were carried out to evaluate the performance of the water-impervious structure applied to the developed cable, ultimately confirming that the WIAL was equivalent to the WILL of established track record and that the cable would withstand 30-years of use.

3.2.1 Water Permeation Measurement

Water permeation was measured simulating the permeation of water from the outside, in which a cable sheath alone was submerged into hot water followed by measuring the amount of permeated water to obtain water permeation.

Figure 2 and Table 5 show the results of measurement together with the water permeation.

3.2.2 Thermo-Mechanical Characteristics Test

The cable was tested to see whether cracks occur in the WIAL by expansion and contraction due to 30 years of heat cycle. The expansion of the cable caused by temperature rise due to current loading was measured, and it was investigated whether cracks occur when a strain corresponding to this expansion was applied to the WIAL, while the S-N characteristic of the WIAL was obtained in advance to support this investigation.

Table 5 and Figure 3 show the results of the strain measurement and the S-N characteristic curve.

4. DESIGN OF JOINTS FOR 22-KV XLPE CABLE WITH REDUCED INSULATION THICKNESS HAVING WIAL

4.1 Target Characteristics and Structure

Development objectives are straight joint, Y-branch joint, and terminating joint and their target characteristics are shown in Table 6. Whereas the electric characteristics are in compliance with JEC-3408-1997 [1], the lightning impulse test voltage is ±135 kV since the LIWV is given as 95 kV.

As for the water-imperviousness of the joints, since there are no standards for joints, it was fixed at a value equivalent to that of heat shrinkable WILL which has an established track record in the water-impervious terminations for metal-sheathed cables of 66-kV rating or over.

4.2 Design Details

Figure 4 shows the structure of the developed straight joint.

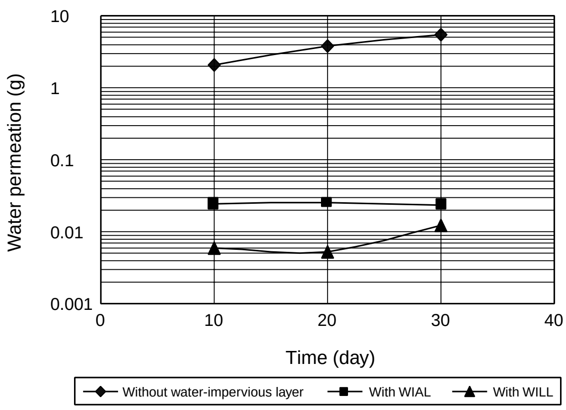


Figure 2 Results of water permeation measurement of cable

Table 4 Measured water permeation of cable

	Present 22-kV CV cable with no impervious layer	Developed cable with WIAL	Reference cable with WILL
Averaged water permeation	1.32×10^{-6}	8.73×10^{-9}	1.93×10^{-9}

Water permeation unit: g·(cm/cm^2)·day·mmHg

Table 5 Estimated strains of the sheath due to temperature change

Category	Accumulated strain cycle	Strain
Diurnal temp. change (once a day)	10,950	0.38%
Short-duration temp. change (once a year)	30	0.61%
Annual temp. change (once a year)	30	1.05%

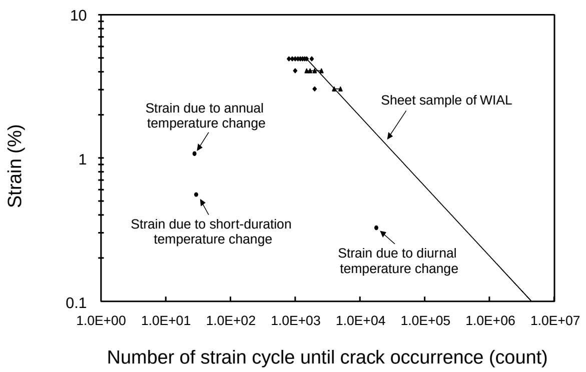
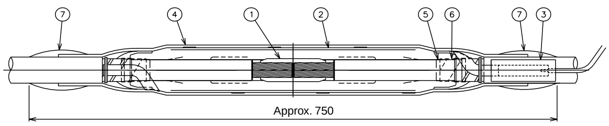


Figure 3 Results of S-N characteristic test

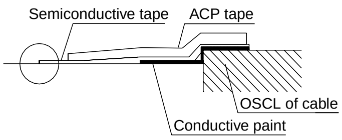
Table 6 Target characteristics of joints

Item	Target characteristics
Partial discharge	10 pC or less at 17 kV (in conformity to JEC-209)
AC withstand voltage	45 kV•1 hr
Lightning impulse voltage	±135 kV•3 repetitions (LIWV = 95 kV)
Long-term loading (in air)	20 kV loading; Conductor temperature: 90°C 8 hr ON / 16 hr OFF, 180 repetitions
Current loading	26.2 kA•2 sec, No abnormalities should be observed
Water-tightness	External pressure: 98 kPA•1 hr, No water permeation should be observed
Water imperviousness	Equivalent to heat shrinkable WILL



No.	Name	No.	Name
4	Water-impervious shrinking tube		
3	Grounding terminal	7	Waterproofing tape
2	Cold shrinkable splice housing	6	ACP tape
1	Conductor sleeve	5	Semiconductive tape

Figure 4 **Straight joint for 22-kV XLPE cable with reduced insulation thickness having WIAL**



Heat-shrinkable tube is heated using a hair drier, smoothing the edge by the heat and the tube's contraction force

Figure 5 New processing method for the edge of OSCL

Considering cost reduction by eliminating spacer sleeve covers together with easy installation at the site, a cold-shrinkable type was employed for insulation, in which a cold-shrinkable splicing housing was expanded at the factory in advance and was subsequently installed by on-site shrinking. As for the material of the splicing housing, silicone rubber was employed for its excellent electrical as well as permanent set characteristics. While permanent set is one of the most important key factors in the application of cold-shrinkable technology with factory expansion, the use of silicone rubber with excellent permanent set performance enables to suppress degradation of interfacial pressures satisfactorily during the entire service period of 30 years.

Additionally, whereas the reduction of the insulation thickness increased the electric field intensity on the insulator surface, the conventional method for processing the OSCL of 22-kV class, i.e., ACP tape wrapping on the OSCL became unable to meet the target performance requirement in terms of partial discharge characteristics. Therefore, a new OSCL processing method of "conductive paint coating plus semiconductive tape wrapping" was developed as illustrated in Figure 5.

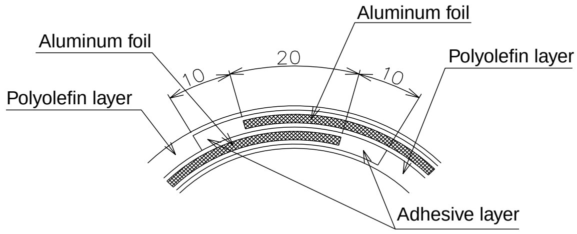
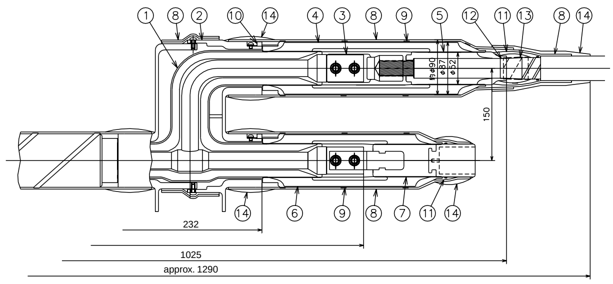


Figure 6 Cross-section of a shrinkable with aluminum water-impervious layer



No.	Name	No.	Name
7	Insulating cover	14	Sealing tape
6	Splice housing (B)	13	ACP tape
5	Spacer	12	Conductive paint
4	Splice housing (A)	11	Self-bonding semiconductive tape
3	Terminal lug	10	Terminal lug
2	Metal housing	9	Grounding wire
1	Main body	8	Water-impervious shrink tube

Figure 7 Y-branch joint for 22-kV XLPE cable with reduced insulation thickness having WIAL

In this method, semiconductive paint that had been successfully applied in the class of 66-kV rating or over was coated over the edge of the cable OSCL to eliminate triangular voids thereof, thus improving the partial discharge characteristics. Furthermore, semiconductive tape was wrapped for protection against possible peeling due to clamping wedge in the case of pre-molded type joint, followed by a smoothing process in which a heat-shrinkable tube --to be removed after the process-- and a hair drier were used to make the edge of the tape level with the surface of the cable insulator, thereby enabling suppression of the voids while making this structure applicable to all types of such joints. By applying this method, a partial discharge start voltage of 30 kV or more was realized even with the cable insulation thickness of 4.5 mm including ISCL.

A shrinkable tube with aluminum water-impervious layer was employed for the water-impervious structure. The tube consists of polyolefin shrinkable tube and water-impervious aluminum layer sandwiched therein, and the structure is such that each layer is firmly bonded together by an adhesive layer, enabling control of water permeation by adjusting the lapping width of the water-impervious layer. By shrinking the tube on its entire length, the straight joint can be made as impervious to water as the cable.

Figure 6 shows the cross-section of a shrinkable tube with aluminum water-impervious layer.

Figure 7 shows the structure of a Y-branch joint developed this time. The joint employed, attaching much impor-

Table 7 Results of the initial and breakdown characteristic tests of 325-sq joints

Test item	Test results
Partial discharge test	No occurrence (Occurrence voltage of 30 kV or more was confirmed)
Lightning impulse withstand voltage	±135 kV·3 repetitions: Good
Lightning impulse breakdown (10 kV·3 step-ups)	S-joint: -395~-425 kV Y-joint: -205~-215 kV
AC withstand voltage	45 kV·1 hr: Good
AC breakdown (10 kV·1 hr step-ups)	S-joint: 145~185 kV Y-joint: 75~95 kV
Current loading	Good (Residual performance was the same as for the initial)
Water-tightness	Good

Table 8 Results of long-term tests of 325-sq joints

Test item			Test results
Long-term loading test (in air and in hot water)			No abnormalities
Residual characteristics after long-term tests	Partial discharge test		No occurrence (Occurrence voltage of 30 kV or more was confirmed)
	AC break-down	S-joint	In air: 115~165 kV In hot water: 135~145 kV
		Y-joint	In air: 85~95 kV In hot water: 85~95 kV
	Lightning impulse breakdown	S-joint	In air: -345 kV In hot water: -345 kV
		Y-joint	In air: -335 kV In hot water: -275 kV

Note
60°C hot water long-term tests were carried out at the Central Research Institute of Electric Power Industry.

tance to cost reduction, a three-layered rubber mold structure with outer casing of metal, terminal lug jointing for conductor joints, and the "splice housing plus spacer" structure for insulation. In terms of OSCL edge processing and the water-impervious structure, the same method and structure as for the straight joint were applied.

5. EVALUATION OF JOINTS

5.1 Initial Characteristics

It was confirmed that the initial characteristics of the joint satisfactorily met every requirement of target characteristics. Table 7 shows the results of the initial characteristics tests together with the breakdown tests that were conducted to know the ultimate performance.

5.2 Long-Term Test

Long-term test of 180-days duration was carried out to confirm the long-term performance of the developed joints, and Table 8 shows the results.

In this test, no abnormalities such as breakdown were found. Furthermore, the residual performance tests after the long-term test were conducted in terms of partial discharge, AC breakdown, and lightning impulse, verifying that the performance was the same as for the initial characteristics as shown in Figure 8.

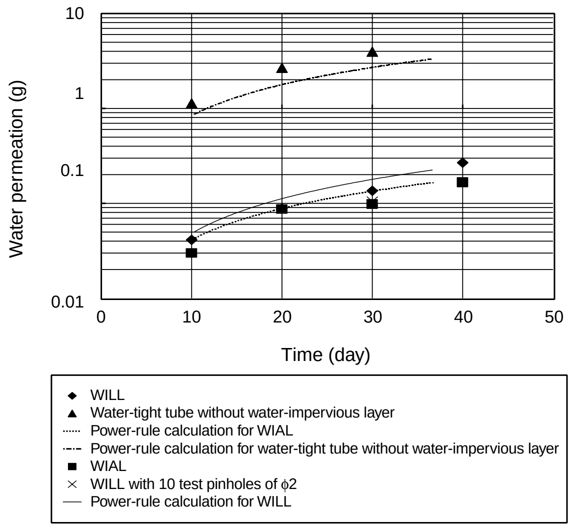


Figure 8 Results of water permeation measurement of joints

Table 9 Results of water permeation measurement of joints

Test item	Test conditions	Test results
Inner-pressure tightness	No air-leak should be observed at 49 kPa·24 hr in 60°C water	Good
Water permeation measurement	Water permeation after 10, 20, and 30 days of immersion in 60°C water to be measured and compared with WILL	Good
Thermo-mechanical characteristics	No crack should occur when following strains are applied Diurnal strain: 10,950 count Short-duration strain: 30 count Annual strain: 30 count	Good

5.3 Water-Imperviousness

The following tests were carried out to evaluate the performance of the water-impervious structure applied to the developed joints, confirming that the water-imperviousness of the shrinkable tube with WIAL was equivalent to the WILL of established track record.

Table 9 and Figure 8 show the results of the tests.

5.3.1 Inner-Pressure Air-Tightness Test

The water-impervious structure was tested whether it could withstand the pressure increase within the joints.

5.3.2 Water Permeation Measurement

The water permeation of WIAL and WILL was measured and compared in accordance with the water permeation measuring methods of CV cables with 66-kV rating or over.

Table 10 Comparison of installation work

[Straight joint]

Item	Joint currently in use	Joint developed
Splice housing mounting	Dedicated tool is used since manual insertion is difficult	Neither skill nor tools required thanks to cold-shrinkable splice housing
Shrinkable tube mounting	Heat source required	The same as for the waterproof tube in present use
Finished dimensions	ϕ 130 x 1150 (mm)	Downsized to about 60 % of current joint

[Y-branch joint]

Conductor splicing	Dedicated tools required for wedge splicing within the Y-branch body	Bolt connection using terminal lug outside the Y-branch body, ensuring secure connection without using dedicated tools
Finished dimensions	W150 x H292 x L1260 (mm)	Downsized to about 90 % of current joint except for the equivalent total length

5.3.3 Thermo-Mechanical Characteristics Test

Thermo-mechanical characteristics were evaluated based on a method that is basically the same as that described in Clause 3.2.2.

5.4 Installation Work

Ease of installation of the joints was evaluated and it was verified the developed joints could be installed in a shorter time than the conventional slip-on type straight joint or prefabricated type Y-branch joint. Table 10 shows the comparison, and Photos 1 and 2 show the installed straight joint and Y-branch joint.

6. CONCLUSION

We have developed a new cable with reduced insulation thickness having water-impervious layer in conjunction with its joints for 22-kV power supply systems in which future application is expected to expand. The development program was aimed at cost reduction through insulation thickness reduction while maintaining reliability and improved environment-friendliness.

Last but not least, we would like to thank Mr. Takeda, Chief Researcher of the Central Research Institute of Electric Power Industry for his great help in carrying out the long-term loading test in hot water.

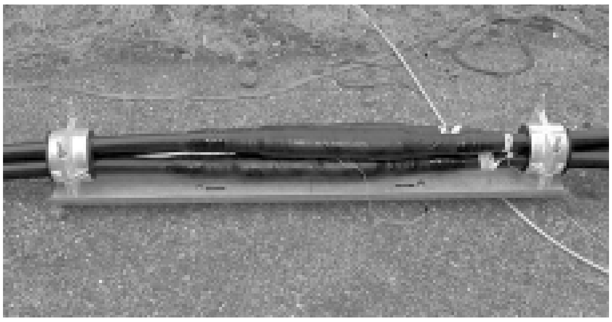


Photo 1 Appearance of installed straight joint

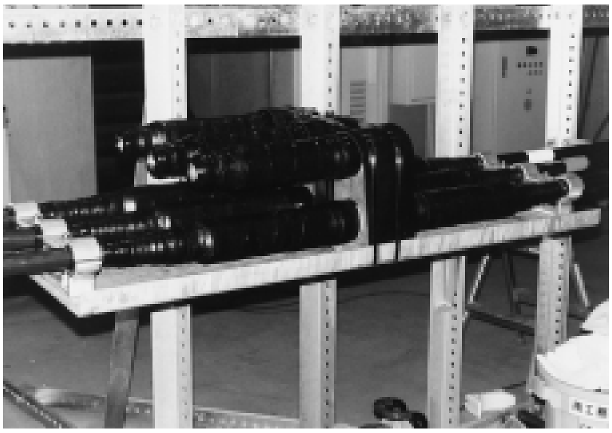


Photo 2 Appearance of installed Y-branch joint

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