Development of a High-Strength Conductor, Accessories and Stringing Method for an Over-Water Crossing of the Osaki Thermal Power Line

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ABSTRACT The Osaki Thermal Power Line, which traverses Japan's Inland Sea area, is one of the world's largest overhead power transmission lines having two water crossings. To assure adequate over-water clearance for these crossings, a 690-mm^2 internally corrosion-proofed KTACSR/EST conductor has been developed, combining high strength and corrosion resistance. It is one of the world's largest conductors providing both high strength and large current-carrying capacity. Cross-wire dampers were also developed to suppress the aeolian vibration that can occur on long spans, together with dead-end clamps for high-strength conductors. Systems for the supervision of helicopter stringing and for over-water supervision were also developed to assure the smooth progress of the conductor stringing work. New aluminum come-alongs were also developed to replace the steel type used previously, reducing mass by approximately 40% and improving stringing efficiency. The stringing method adopted was the semi-prefabrication method, in which the length of conductor to be cut is determined on the basis of measurements of sag made after temporary tensioning.

The overhead water crossings were strung using the conductor, accessories and stringing method described here, and the work was successfully completed in October, 1997.

1. INTRODUCTION

The Osaki Thermal Power Line is a 220-kV transmission line running from Chugoku Electric Power's Osaki Power Station on the island of Nagashima in the Inland Sea to the Kurose Substation in the town of Kurose, Hiroshima Prefecture. The route involves two water crossings--1,603 m from Nagashima to Usujima, and 2,145 m from Usujima to the mainland, and is one of the largest such overhead lines in the world.

Furukawa Electric was in charge of the high-strength conductor, accessories and stringing method for the 1,603-m Nagashima-Usujima sector, and completed the work successfully in October, 1997.

The conductor used was a high-strength type for improved sag characteristics, and new stringing techniques were introduced in consideration of safety and working

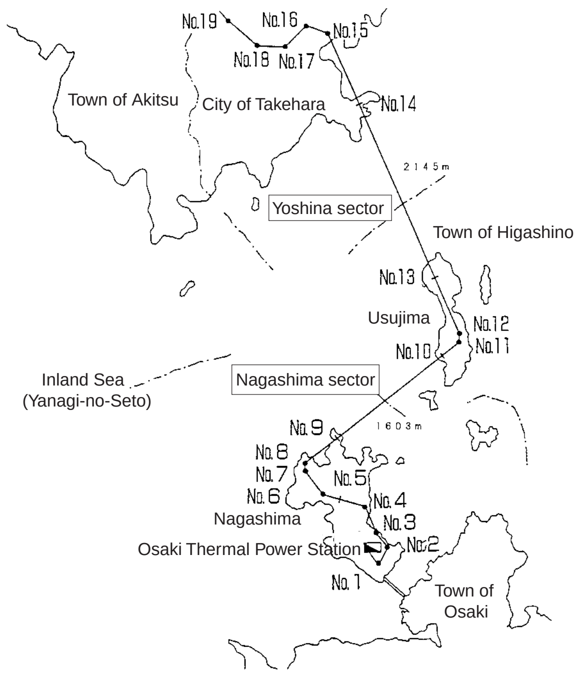

Figure 1 Route of the Osaki Thermal Power Line showing over-water sectors

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convenience.

This paper describes in detail the development of the high-strength conductor, accessories and stringing methods used on this over-water portion, and describe the stringing work.

2. CONSTRUCTION OVERVIEW

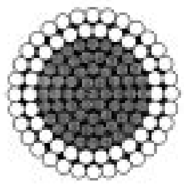
The line runs from Nagashima via Usujima to Yoshina in Takehara, and comprises two water crossings--the Nagashima sector (towers No. 8 through No. 11) and the Yoshina sector (towers No. 12 through No. 15). Figure 1 shows a map of the route.

3. DESIGN

3.1 Conductor

Since the route of the line crosses shipping lanes, it was decided to provide sufficient clearance--28.4 m on the Nagashima sector and 44.4 m on the Yoshina sector--so as not to interfere with shipping. It was also considered desirable, from both the economic and the environmental points of view, that the towers on the Nagashima sector be as low as possible, and to effect this improvement in sag characteristics required a special conductor that could be used under extremely high tensile strain. It was also essential that the conductor be capable of carrying a large current--1,360 A or more--and be able to withstand severe salt corrosion. After considering conductors of 7 different structures, a 690-mm^2 stranded aluminum conductor with an internally corrosion-proofed special steel core (KTAl 58 strands/3.9 mm + Est 61 strands/3.3mm). Table 1 shows conductor specifications.

Table 1 Specifications of 690-mm^2 KTACSR/EST Conductor

Item		Unit	Characteristic
Type of wire		-	Internally corrosion-proofed KTACSR/EST
Nominal cross-sectional area		mm^2	690
Cross sectional view			
Stranding structure	KTAL	strands/mm	58/3.9
	EST	strands/mm	61/3.3
Min. tensile load		kN {kgf}	979.6 {99,680}
Outside diameter	KTAL	mm	45.3
	EST	mm	29.7
Cross-sectional area	KTAL	mm^2	693.1
	EST	mm^2	521.7
	Total	mm^2	1,215
Mass	KTAL	kg/km	1,928
	EST	kg/km	4,130
	Grease	kg/km	231
	Total	kg/km	6,289
Electrical resistance		W/km	0.0465
Coefficient of elasticity		GPa{kgf/mm^2}	124.7 {12,720}
Coefficient of linear expansion		/˚C	14.9×10^{-6}
Current-carrying capacity	Continuous (150˚C)	A	1,969
	Short term (180˚C)	A	2,266

This conductor is made by multilayer stranding of 61 1,770-MPa (180 kgf/mm^2) class 3.3-mm diameter extra-strong galvanized steel wires, stranded together with 58 3.9-mm high-strength heat-resistant aluminum alloy wires, with an aluminum-to-steel ratio of 1.33 and a tensile load of 979.6 kN (99,680 kgf). As a measure against salt corrosion, the conductor is "internally corrosion-proofed," i.e., packed with corrosion-proofing grease down to the inside of the outer layer, and to prevent rotation of the conductor during stringing, it is right-hand laid to match the direction of the stringing wire.

In the past there have been few instances in which the high-strength conductors used in over-water crossings also provided large current-carrying capacity. The conductor here used for the Osaki Thermal Power Line can be regarded as the world's largest high-strength high-current conductor.

3.2 Vibration Dampers

The maximum tensions applied to this conductor are extremely high, reaching 287.3 kN (29,000 kgf), and the normal tension is relatively high, at 25% of the tensile strength of the conductor. It is therefore necessary, in designing the vibration dampers, to take particular note of conductor damage resulting from aeolian vibration. Studies were therefore undertaken to design a cross-wire damper (CWD) based on existing wind data and on the experience previously gained in designing the Matsushima Thermal Line.

Mounting the CWD on the conductor by applying cross wires of appropriate length at an angle of 45° to the line causes the cross wires to resonate when aeolian vibration is produced in the conductor, so that the energy is canceled out by the elastic hysteresis loss of the cross wires, vibration interference and torsional movement, and conductor vibration is suppressed.

On the one hand, the large amount of energy input when the span is long requires that the CWDs also be large, while on the other, ease of installation and the problem of strain on the towers necessitate reduced size and weight. Accordingly, with a view to easier installation, the CWDs were designed as combinations of lengths of 2 - 5 m. And although it is normal practice to make the cross wires of the same material as the line conductor, in this case con-

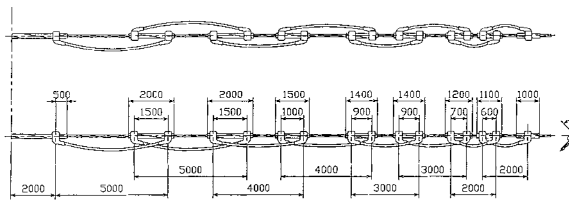


Figure 2 Configuration of the CWD8 8-loop cross-wire damper

ductor stock was used only for the 5-m loop, and the other loops were made of 980-mm^2 ACSR. It was thus possible to decrease weight while suppressing a broader range of frequencies. Figure 2 shows the mounting configuration.

3.3 Dead-End Clamps

The dead-end clamps, like those for (T) ACSR in the JEC standards, were of compressive-type construction, comprising a steel clamp for holding the steel core, an aluminum clamp for holding the aluminum wire, and a jumper socket for holding the jumper wire. Because of their size, however, there was fear that with the ordinary method of clamping, unraveling of the conductor might occur. Reverse compression was therefore adopted for the aluminum clamp. The following factors were considered in determining clamp structure:

1) A draw-out plate was used in the aluminum compression mechanism, to the mount of which was welded a cast iron socket. By this means differences in inner diameter were reduced and it was possible to maintain a virtually constant amount of elongation during compression.
2) To absorb differences in elongation at compression, an aluminum ring was mounted between the aluminum clamp and the steel clamp.
3) Since the ratio of tensile load borne by the steel core is large, the outer diameter of the compressing mechanism of the steel clamp was made larger than that of the stranded wire. This means that the aluminum wire compressing mechanism requires a collar, and to facilitate the compressing work, a unitized structure was adopted in which this collar was welded to the inner surface of the aluminum clamp.

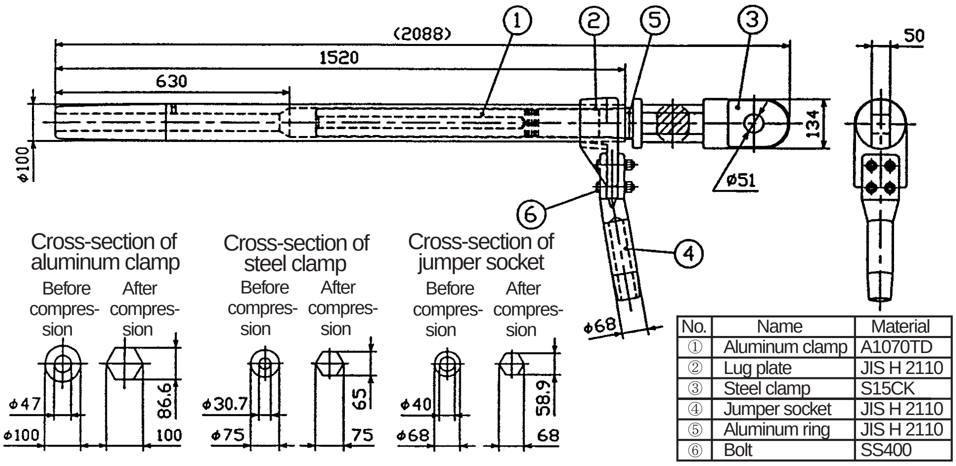
Figure 3 shows the clamp.

3.4 Lightweight Come-Alongs

Because of the high tensile load on the conductor, come-alongs of conventional design would have been too large and massive. Accordingly a new and lighter design was developed made of METACS--a compound material consisting of aluminum alloy and ceramic--with a hanger made of the AL7000 alloy used in aircraft. This resulted in a unit that had the same strength as conventional types but only about 40% of the weight.

Table 2 Evaluation Tests

Test subject	Test item		Purpose
Stranded wire	Current capacity test	AC resistance	To confirm influence of skin effect, iron loss etc.
		Temperature rise	To compare and verify calculated and measured values
	Stress elongation	Coefficient of elasticity	To compare and verify conventional and measured values
		Distributed stress for aluminum	To compare and verify calculated and measured values
	Creep characteristics	At room temperature	To take account of tensioning temperature
		At elevated temperature	
	Vibration test		To confirm fatigue limiting stress
	Corrosion	Salt spray	To confirm corrosion resistance
		Grease softness	To verify heat-resistance of grease
Vibration dampers	Absorbed energy characteristics		To verify vibration damping performance
	Strength of holding mechanism		To confirm the strength of the holding mechanism fittings
	Strength of compressive mechanism		To verify the strength of the compressive mechanism of the clamp
	Holding force		To verify the conductor holding force
	Anti-fatigue strength		To confirm loosening of bolts during vibration, etc.
Dead-end clamps	Heat cycling		To verify strength after heat cycling
	Tension test		To verify breaking strength
Lightweight come-alongs	Holding force test		To verify wire holding force at actual tension



No.	Name	Material
①	Aluminum clamp	A1070TD
②	Lug plate	JIS H 2110
③	Steel clamp	S15CK
④	Jumper socket	JIS H 2110
⑤	Aluminum ring	JIS H 2110
⑥	Bolt	SS400

Figure 3 Compressive-type dead-end clamp for 690-mm^2 KTACSR/EST conductor

4. CHARACTERISTIC CONFIRMATION TESTS

In addition to general performance tests, the conductor and accessories were subjected to the performance evaluation tests in Table 2. Satisfactory results were obtained.

The results of tests to confirm the vibration performance of the CWDs showed that for conductor alone, a distortion of ±110µm was produced at frequencies of 30 Hz and below, whereas with the vibration damper mounted this was reduced to ±30µm (see Figure 4).

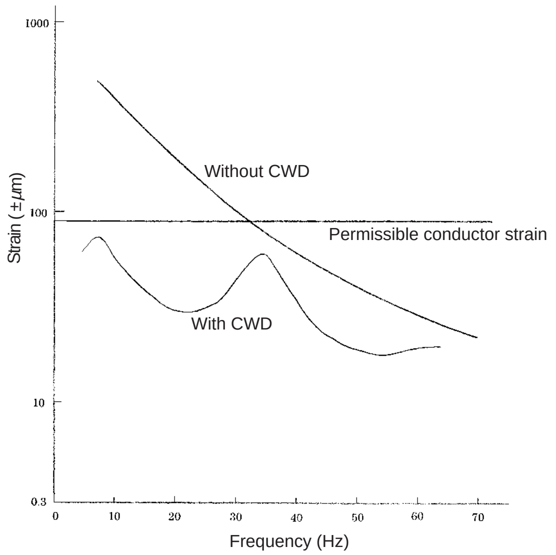


Figure 4 Maximum anticipated strain on 690-mm² KTACSR/EST conductor with and without CWD8 damper

5. STRINGING METHOD

Among methods that can be used for stringing the pilot rope for over-water crossings are by float, by crane barge and by helicopter. The committee responsible for the safe installation of line decided to adopt a helicopter method that used loop stringing, which is considered the most reliable for installing a conductor on a water crossing. Figure 5 shows the main machinery and equipment used.

5.1 Preparation

The machinery and equipment used was refurbished and improved from that used to install Chugoku Electric Power's South Hiroshima connector, which was completed in June, 1981. A series of verification tests were carried out to confirm working convenience and safety. Table 3 shows the verification tests. And to assure safety and working convenience at the drum engine area (tower No. 8) and the return pulley area (tower No. 11), large inclined stages made of steel and scaffolding pipe were erected (see Photo 1).

Photo 1 No. 8 tower, drum yard and large inclined stages

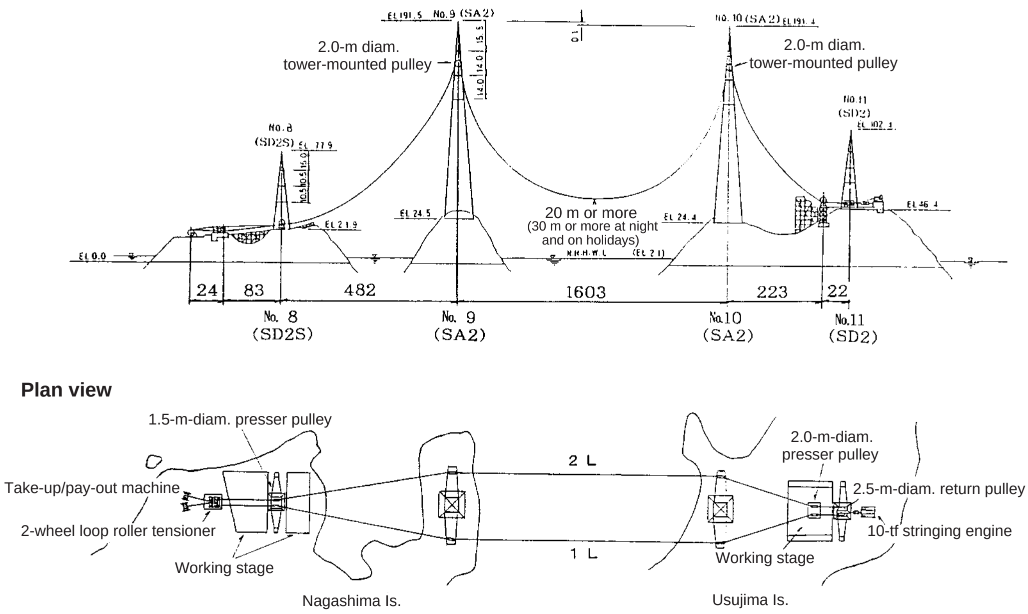


Figure 5 Equipment setup for stringing on the Nagashima-Usujima sector

Table 3 Verification Tests

Test item	Purpose
Loop roller/tensioner load test	To confirm temperature and strain in main roller/tensioner components under continuous operation.
Roller/tensioner pass-through test (temporary connection section)	To confirm pass-through characteristics of temporary connection section
Movement characteristics test (loop roller/tensioner, take-up and pay-out machines and control equipment)	To verify movement characteristics of equipment and techniques of operation
Tensioning in anti-tension devices	To subject all tools and methods subjected to individual evaluation tests to tensioning in the anti-tension to confirm whether there are any problems with the methods
5-wheel block strength test	Breakdown test of the 5-wheel block used in tensioning
Conductor car test	To evaluate the suitability of the conductor car used in mounting the dampers using a full-scale model.
Reverse T ladder test	To evaluate the suitability of the ladder used in mounting the accessories using a full-scale model.
Helicopter stringing flight test	To conduct helicopter stringing under conditions as close as possible to actual conditions, and confirm the condition of the roller/tensioner, helicopter and stringing rope.

5.2 Helicopter Stringing

It was decided to develop roller/tensioner machines using high-performance brakes, etc. and to conduct verification tests of helicopter stringing techniques in mountainous terrain using spans of the same length as the crossing.

Based on a survey of ship traffic in the area, it was decided to carry out the helicopter stringing operation between 9:00 and 11:00 a.m. on June 5, 1997. The operation was completed safely and effectively, using a warning vessel, marine monitoring station, radar, and so on. The helicopter used was an SA330J Puma from Aerospaciale, using a 12-mm-diam. pilot rope made of strong, lightweight Kevlar fiber and keeping the rope 45 m or more above the surface of the water. The stringing took approximately 30 min per rope, enabling both ropes to be strung within the allotted time.

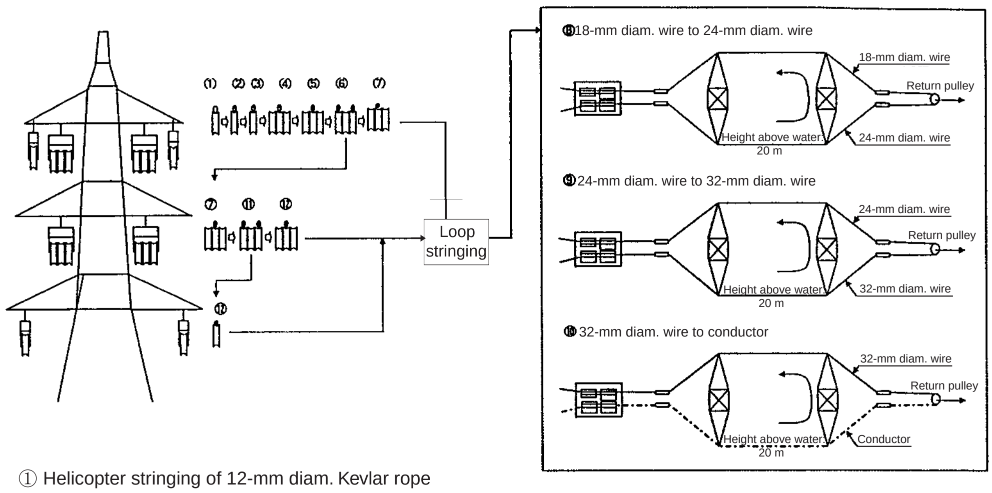
5.3 Conductor Stringing (Loop Stringing)

Due to the high stringing tension on the conductor (approximately 180 kN or 18 tf), the need to maintain the wire at an over-water clearance of 20 m or more (or 30 m or more at night and on holidays when no monitoring personnel are present), and the need to increase conductor height temporarily during the passage of large ships, it was decided to use the loop stringing method, which allows wire and conductor sag to be easily adjusted during the stringing process.

The loop stringing method involves providing a loop roller tensioner and a return pulley on opposite sides of the water, and starting from the Kevlar rope strung by the helicopter, gradually increasing rope diameter up to 18 mm, at which point a loop is formed and wire diameter is increased from 18 to 24 mm, from 24 to 32 mm, and finally from 32-mm wire to the conductor. Figure 6 shows the basics of the method.

The height of the wire or conductor can then be easily adjusted during stringing by moving the return pulley, which is positioned on a rail.

A method was also adopted to minimize the increase in tension when temporary joints passed through the loop roller/tensioner and to prevent damage to the groove of the roller/tensioner.



① Helicopter stringing of 12-mm diam. Kevlar rope
② 12-mm diam. Kevlar rope to 14-mm diam. Kevlar rope
③ 14-mm diam. Kevlar rope to 14-mm diam. wire
④ Restringing of 14-mm diam. wire from single to triple pulley
⑤ 14-mm diam. wire to 18-mm diam. wire
⑥ 18-mm diam. wire to two strands of 18-mm diam. wire
⑦ Restringing of 18-mm diam. wire

⑧ 18-mm diam. wire to 24-mm diam. wire
⑨ 24-mm diam. wire to 32-mm diam. wire
⑩ 32-mm diam. wire to conductor
⑪ 18-mm diam. wire to two strands of 18-mm diam. wire
⑫ Restringing of 18-mm diam. wire
Thereafter repeat steps ⑧ through ⑩

Figure 6 Method of loop stringing

5.4 Monitoring Systems

5.4.1 Monitoring System for Helicopter Stringing

A computer was installed in the helicopter cockpit and in the operating room at tower No. 8, and information sent from the global positioning system (GPS), air-pressure altimeter, load cell, etc. were used to effect real-time monitoring of the sag of the stringing rope on the computer screens. This stabilized the stringing operation, greatly contributing to the safety of the work (see Figure 7).

5.4.2 Marine Monitoring System

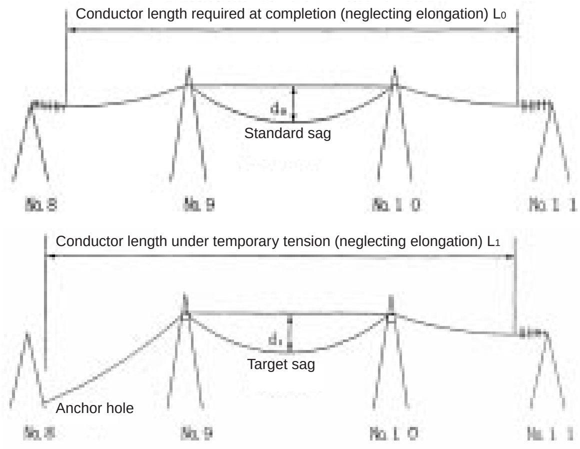
Since it was possible that ships with masts 20 m or more in height might pass under the site of the stringing operation, efforts were made to ensure the safety of shipping by setting up a marine system to provide ordinary monitoring by human operators and a warning vessel, together with radar observation of shipping. This would enable early identification of those of the many ships passing through that would pose a danger of striking the stringing wire or the conductor. Radar was used to locate ships within a radius of 6 km from the work site, so that the mast-top of a likely vessel could be sighted through a transit, its mast height and compass heading calculated by computer and the vessel followed by closed-circuit TV. In this way information on the passage of large ships can be obtained early.

6. TENSIONING

6.1 Semi-Prefabrication Construction Method

Because of the high tension on the conductor (approximately 20 tf/conductor) and the difficulty of setting the compressive clamp on the tower, and to increase the working convenience, a semi-prefabrication method was used. In this method, the actual conductor length at completion is subtracted from the actual length when temporarily tensioned, and the conductor is cut on the ground, clamped and strung (see Figure 8).

1) Based on the results of precise optical-wave measurements between the support points on each tower and between the anchor at tower No. 8 and the support point of tower No. 9, calculations of sag and tension were performed using a mainframe computer to find the actual length of conductor required at completion.
2) After attaching the conductor at tower No. 11, the other end was fastened to the dead-end clamp of the anchor beneath tower No. 8 and tensioned to the target sag (approximately 80% of the standard sag) to find the actual length under temporary tensioning.
3) A correction factor was found to compensate for such factors as steel clamp length, clamp elongation at com-



L' = (L_1 – L_0)

L_1 = Conductor length at temporary tension (neglecting elongation)
From base anchor at tower No. 8 to conductor ending in dead-end clamp at tower No. 11
L_0 = Conductor length required at completion (neglecting elongation)
From conductor ending in dead-end clamp at tower No. 8 to conductor ending in dead-end clamp at tower No. 11
L' = Cutting compensation length
From base anchor at tower No. 8 to point at which conductor is cut

Figure 8 Method of semi-prefabricated stringing

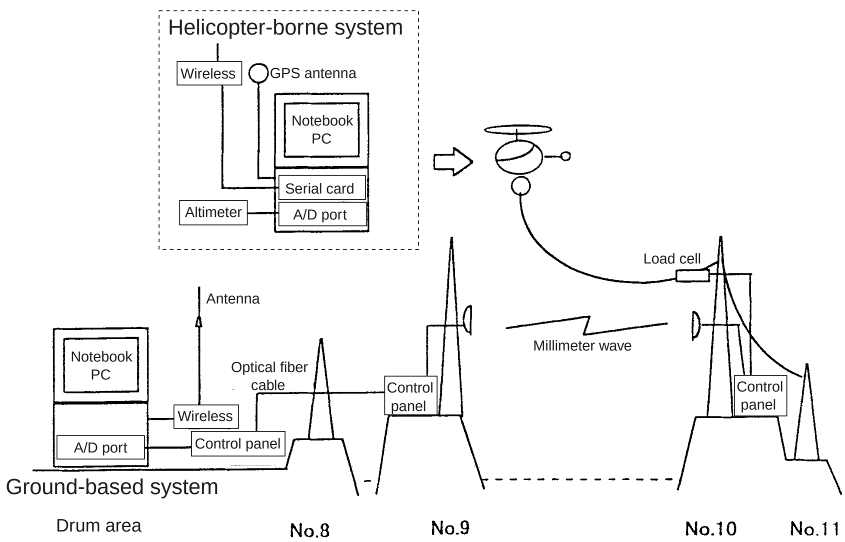


Figure 7 Monitoring system for helicopter stringing

pression, elongation of ganged anti-tension insulators, tower flexure, etc., to correct the actual conductor length at completion and under temporary tensioning.

The corrected length cut was then determined from the above calculations and the temperature of the conductor during temporary tensioning.

6.2 Tensioning

When loop stringing of the conductor was completed, the conductor loops and presser pulleys were disassembled using 5-wheel and 4-wheel prestretch blocks, the conductor was moved to the 25-tf anchor at the foot of tower No. 11, cut at the designated position, and fastened to the dead-end clamp.

After completion of clamping, the 4-wheel prestretch blocks on the tower and on the ground were set, and the conductor was mounted to the anti-tension device by means of a prestretch block method that dispenses with the come-along.

After mounting to tower No. 11, the conductor was temporarily tensioned on the ground at tower No. 8 using the semi-prefabrication method, the dead-end clamp was fastened and mounted on the anti-tension device by a wire-type method without come-along, thereby completing the tensioning operation. Note that to prevent twisting of the tower, the tensioning and clamping operations were performed simultaneously for both circuits (see Photo 2).

Photo 2 Tensioning at tower No. 8

7. CONCLUSION

The stringing of the Osaki Thermal Power Line--the last and largest line in this century with a water crossing--was competed on time and without problems. It was an excellent example of coordination among the power utility, equipment manufacturer and construction personnel. The conductor, accessories and basic design of this project were developed around 1980, and its successful completion is a tribute, not only to those actually engaged in the manufacture, development and construction, but also to those who participated in the original design and development.

The authors would like to express their deep appreciation to all those involved.

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