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FEATURED TOPIC

Wireless Communication Based Automatic Tension Control System for Prestressing Steel Strands

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The tensioning process of prestressing steel strands involves introducing the required prestressing force into concrete structures, which is a critical step affecting the structure's durability. Traditionally, this process involved manual operation of tensioning equipment for prestressing steel strands and visual readings of analog gauges for recording, leading to challenges such as labor-intensive processes, measurement errors, and the need for proximity to tensioning equipment. The automatic tension control system automates these tasks using control devices and digital measuring instruments, contributing to reduced manual labor, enhanced accuracy, and improved safety. This paper provides an overview of the wireless automatic tension control system that eliminates the need for communication cable wiring, along with examples of its application and benefits.

Keywords: prestressing steel strands, automation, wireless communication, labor-saving, accuracy improvement

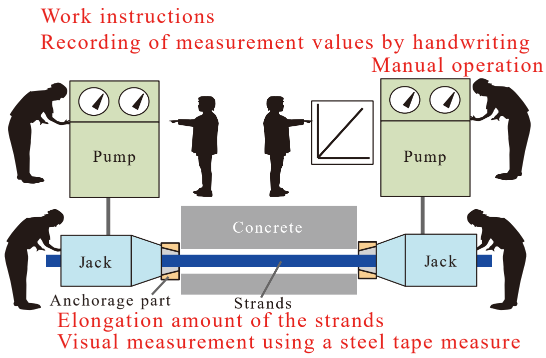
1. Introduction

The prestressed concrete*[1] (hereinafter referred to as "PC") industry is one that requires labor-saving technologies to address the shrinking workforce due to a declining birthrate and an aging population.

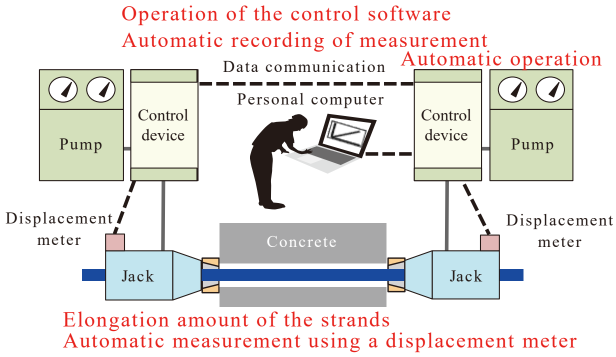
To allow a PC structure to demonstrate its performance, it is essential to apply a specified tensioning force to prestressing steel strands, which are tensioning materials. Thus, tensioning of prestressing steel strands*[2], which applies an appropriate prestressing force to a concrete structure, is a crucial process that affects the durability of the structure. However, conventional tensioning work requires manual operation of the tensioning equipment, visual reading of analog measuring instruments, and manual recording (Fig. 1 (a)). Thus, the work posed issues, such as manpower required for the work, measurement errors due to visual reading of measurement values, and work in proximity to the tensioning equipment in operation.

The authors developed a wireless automatic tension control system for prestressing steel strands (Fig. 1 (b)) as a technology to potentially solve these issues. In this system, a personal computer, control devices for the tensioning equipment, and measuring instruments are linked by wireless communication. Labor savings, higher accuracy, and improved safety can be achieved by automating the operation of the tensioning equipment and eliminating the visual readings that are typically required when tensioning prestressing steel strands.

This paper provides an overview of this system as well as examples and effects of applications.



(a) Schematic diagram of manual tensioning



(b) Schematic diagram of automatic tensioning

Fig. 1. Comparison between manual and automatic tensioning

2. Conventional Tensioning Control Method for Prestressing Steel Strands

In general, when tensioning prestressing steel strands, a hydraulic tensioning jack (hereinafter referred to as the "jack") is installed to the anchorage part*[3]. Then, the hydraulic pressure of the hydraulic pump (hereinafter referred to as the "pump"), which is connected to the jack, is manually controlled. Here, the cylinder moves while holding the prestressing steel strands with a wedge, which is built into the cylinder at the rear end of the jack, to perform tensioning of the prestressing steel strands

(Fig. 2 (a)). To confirm that an appropriate tensioning force is applied to the prestressing steel strands, the control range of (2) the elongation amount of the prestressing steel strands against (1) the tensioning force (a load converted from the hydraulic pressure of the pump) is calculated in advance (Fig. 2 (b)[(1)]) to check that the measurement values of (1) and (2) are within the range (Fig. 2 (b)[(2)]).

However, this work requires significant manpower, as six workers must share tasks: operating pumps while checking the analog hydraulic pressure gauge, measuring elongation by bringing a steel tape measure to the edge of prestressing steel strands (to which a tensioning force of hundreds of tons is applied), and recording the measurement values by hand. In addition, measurement errors occur due to visual reading of measurement values. Work must be performed in proximity to the tensioning equipment in operation. These issues need to be addressed.

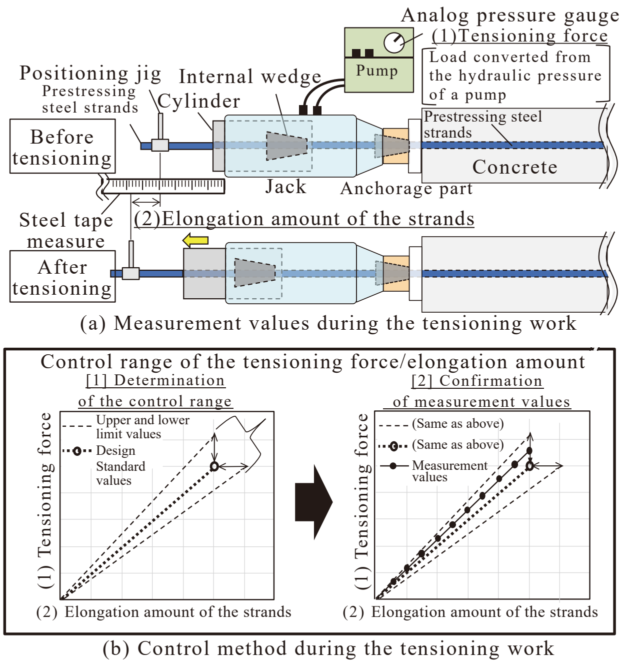


Fig. 2. Overview of the tensioning work and control

3. Wireless Automatic Tension Control System for Prestressing Steel Strands

3-1 System configuration

The schematic diagram of this system is shown in Fig. 3. This system consists of a personal computer, which is used to operate the system, control devices, which control the hydraulic pressure and perform automatic measurement, and laser displacement meters, which measure the elongation amount of the prestressing steel strands, in addition to the tensioning equipment, including jacks and pumps that are also used in conventional manual tensioning. Hydraulic pressure hoses are used for connections between the control devices and the pumps and between the control devices with the jacks. Wireless communication is used for connections between the personal computer and a control device, between the

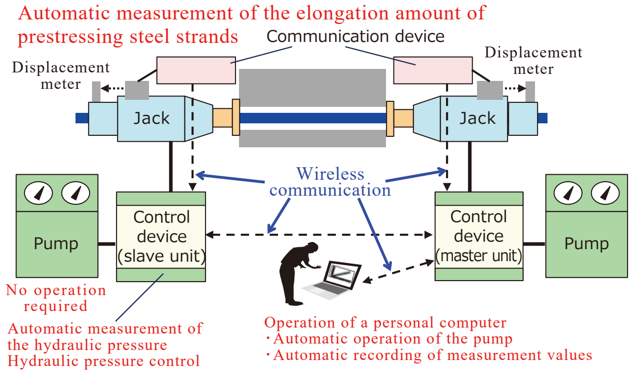


Fig. 3. Configuration of a wireless automatic tensioning control system

control devices and the laser displacement meters, and between the control devices. By operating the personal computer, the control devices automatically manage the hydraulic pressure of the pumps connected to the jacks, thereby performing the tensioning of the prestressing steel strands. The hydraulic pressure data measured by the control devices and the displacement data measured by the laser displacement meters are transmitted to the personal computer and automatically recorded. Wireless connection between each piece of equipment eliminates wiring required for wired connection, contributing to labor saving.

3-2 Overview of the control devices

The control device incorporates a hydraulic pressure circuit and a control unit that feeds oil from the pump to the jack based on commands from the personal computer, as well as a communication device and an antenna for wireless communication with each piece of equipment. The control device has an internal space to store a power supply cable, rotating warning light, pendant switch, and other items, which are connected to the control device.

When performing tensioning work using this system, no workers are present near the pumps. This poses a risk of workers inadvertently coming close to the jacks without realizing that the tensioning work is underway. Thus, a function was added to notify on-site workers that the tensioning work is underway with a lamp and a buzzer by

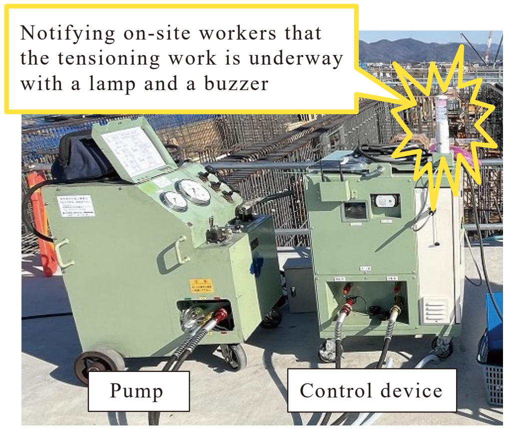


Photo 1. Appearance of the control device and pump

connecting the control device with a rotating warning light, thereby improving safety (Photo 1).

3-3 Overview of the displacement meter

(1) Configuration

The displacement meter measures the elongation amount of the prestressing steel strands due to tensioning and transmits the data to the control device. It is used near the jack, which is used for tensioning the prestressing steel strands. Since many prestressing steel strands must be tensioned, a portable device is required, and a wireless, compact, and lightweight device is desirable in terms of both communication and power supply. We developed a portable displacement meter that meets these requirements, namely, a battery-powered meter capable of wireless transmission of displacement data. To cope with on-site troubles, the meter is also capable of wired communication and external power supply as the backup functions. The schematic diagram of the configuration of the displacement meter is shown in Fig. 4.

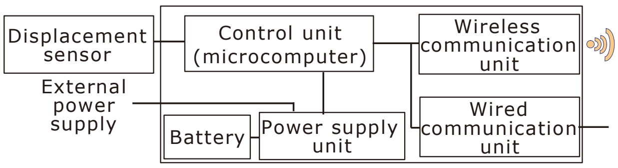


Fig. 4. Schematic diagram of the configuration of the displacement meter

(2) Details

There are various types of displacement sensors. The mechanical type, including wire displacement sensors, may malfunction due to dust and rain at construction sites. Thus, the contactless type was selected. It was decided to use a digital-output laser displacement sensor, which featured a measurement resolution of 0.1 mm and good connectivity with the control unit. With the on-site environment taken into account, a model which worked properly in an operation test under direct sunlight was selected. Components that have been used in large numbers at the plants of our group were selected for the control unit and the wireless communication unit. The displacement meter must be battery-operated, but it is difficult to achieve long operation because the current consumption of the laser displacement sensor and wireless communication unit is relatively high. On the condition that the battery is charged at least after the end of daily operations, it was decided to use a rechargeable battery that was balanced in terms of size to ensure portability and battery life. The function to switch between the external power supply and the battery, the

Table 1. Main specifications of the displacement meter

Displacement sensor	Laser type (displacement resolution: 0.1 mm)
Communication	920 MHz band specified low-power radio
Power supply	Rechargeable battery, external 12 VDC
Size	155 × 135 × 85 (mm), about 920 g

Photo 2. Displacement meter

communication function with the displacement sensor, and the wired communication unit were newly developed to meet the specifications of this equipment. The enclosure was made from mechanically strong resin and was designed to be waterproof for use even in rainy weather.

3-4 Overview of wireless communication

The wireless communication unit conformed to the specified low-power standard for data transmission in the 920 MHz band. It received construction-type certification and did not require licenses for radio stations. The data transmission speed of this standard is lower than that of wireless LAN; however, signal attenuation in the presence of obstacles is relatively minor in this frequency band. The communication traffic of the displacement information was small. Thus, this standard was suitable for the system because there were various on-site obstacles, including heavy industrial machines. The configuration of the wireless system for this equipment is as shown in Fig. 5. There were two communication systems. One was between the master and slave control devices, and the other was for the displacement meter. The communication between the master control device and the slave control device was used for transmission and reception of data required for linkage between the devices. The communication for the displacement meter was used to transmit the displacement values, remaining battery of the displacement meter, and internal temperature from the displacement meter to the control device.

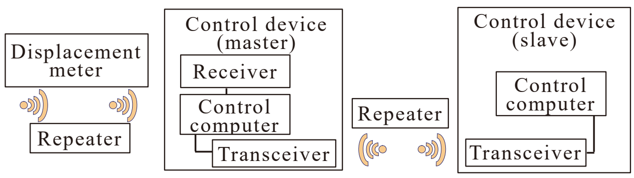


Fig. 5. Configuration of the wireless system

The control device was equipped with a receiver, which was on the other side of the displacement meter, and a transceiver for communication between the devices. Each wireless device was connected to the control computer via Ethernet. The connection interface was MODBUS, which is generally used for plant equipment. In the displacement meter communication, the control computer served as the master equipment and periodically obtained the displacement data from the receiver and the information about the status of the displacement meter. The data and information were displayed on the operator PC screen. Settings, including paring between the displacement meter and the receiver, were performed on the operator PC via a graphical web browser. When the status of wireless communication was poor, a wireless repeater was available as an option. This repeater automatically searched and set communication paths only by setting a communication channel, ensuring the ease of use at construction sites. The use of a repeater enables wireless communication even if the communication distance is long or the system is used inside a bridge with multiple concrete walls, for example.

(a) Receiver (b) Repeater

Photo 3. Communication devices

3-5 Automatic tension control

(1) Workflow

The tension control workflow when using this system is shown in Fig. 6. The control limit and holdback line are displayed in the graph of the software by inputting the results of tension calculations, which were performed in advance, into the tension control software installed on the personal computer and determining the control limits in the software. The use of this system made it possible to automatically perform the work after setting the jack only by operating the personal computer: setting of the initial load and initial elongation value, measurement and recording of the pressure and elongation amount in each tensioning step, final load calculation and final tensioning, anchorage of the wedge, jack depressurization, calculation of the set amount, and jack cylinder return. The tension control diagram can be output to spreadsheet software and can be viewed on a different personal computer.

(2) Features of the software

A screenshot of the software for this system is shown in Fig. 7. Actual measurement values of elongation and pressure were indicated in the upper part of the screen. The tension control graph was shown in the center of the screen. Values of elongation and pressure recorded in each step were presented on the left side of the control graph. The operation panel was displayed on the right side of the control graph. Basically, the button to be pressed next on the personal computer blinked yellow during the automatic tensioning work. Thus, a series of tensioning work, including the initial load tensioning and the jack cylinder return, was performed by pressing the blinking buttons sequentially. Thus, when tensioning was performed continuously for dozens of prestressing steel strands in particular, the operator of the personal computer, who only had to

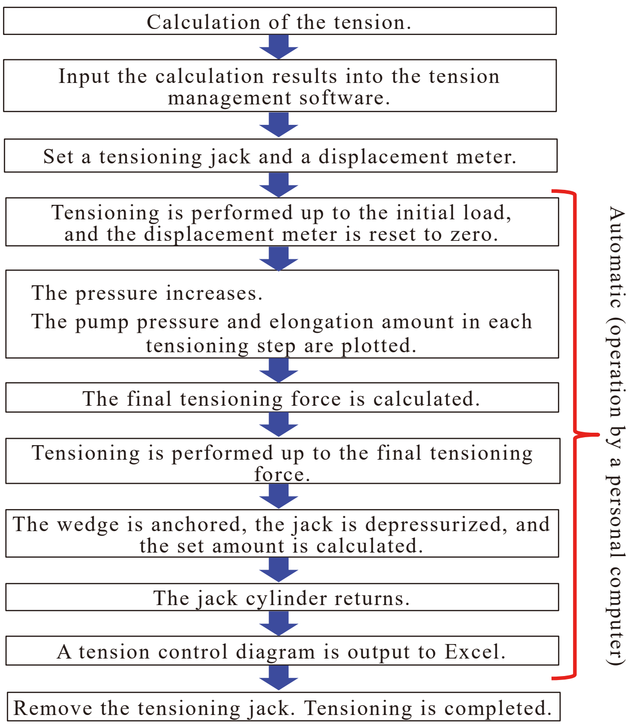


Fig. 6. Workflow of the automatic tension control system

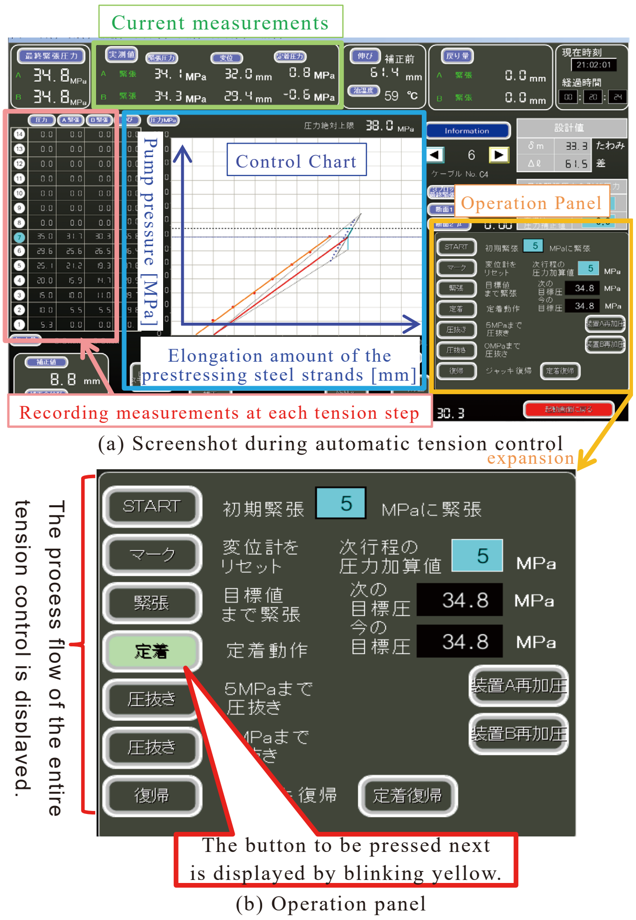


Fig. 7. Screenshot of the software

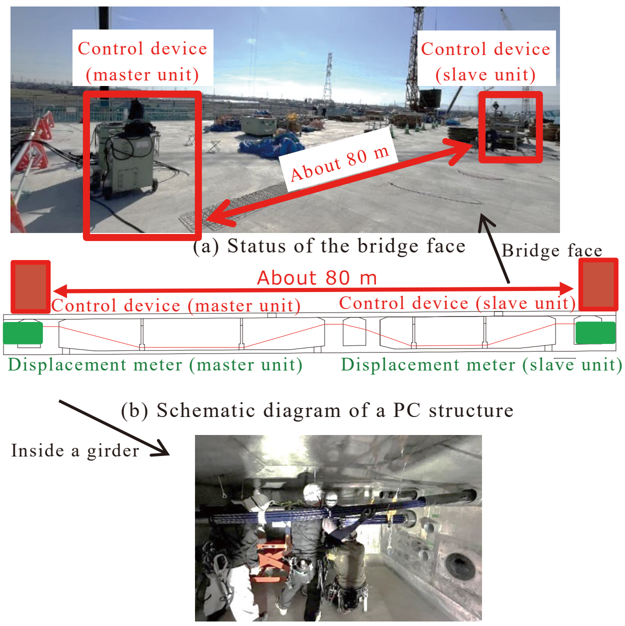
follow the instructions to perform the operation, was likely to become less aware of the current work in the entire tension control process, posing a risk of being unable to give appropriate information to on-site workers.

As a countermeasure, operation buttons were arranged in the order of the tensioning workflow on the operation panel, and the entire flow chart was visualized to help the operator check the current process at a glance. This made it possible to see the overall flow of the tensioning work to control the tension and prevent human error.

4. Application to an Actual Bridge

4-1 Wireless communication

This system was used for tensioning of prestressing steel strands of 100 m long in construction of an actual PC structure (a box-girder bridge, Fig. 8). The two control devices were installed on the bridge face. Although the control devices were about 80 m apart, there were no communication errors or delays in data transmission and reception. The communication signals did not reach when there was an obstacle, such as a crane, between the control devices at the same distance. However, communication was enabled by installing a repeater to bypass the crane without communication error or delay in data transmission and reception. The displacement meters were installed in the box girder, where radio waves of mobile phones did not reach. However, communication was established between the control devices and the displacement meters without communication error or delay in data transmission and reception. The data transmission and reception capability by wireless communication, which did not require wiring work, was demonstrated.



(a) Status of the bridge face
(b) Schematic diagram of a PC structure
(c) Status inside the girder

Fig. 8. Environment in an actual PC structure

4-2 Labor saving and safety improvement

The status of the tensioning work using this system is shown in Photo 4. The conventional tensioning work required six workers in total in the case of two-sided tensioning: two controllers, two workers to operate the hydraulic pumps, and two workers to set the jacks and measure the elongation amount of the prestressing steel strands. However, this system allowed the work to be completed with only three workers: one controller operating the personal computer and two workers setting the jacks, resulting in labor saving of three workers. The two workers who set the jacks no longer had to measure the elongation during the tensioning work. They did not have to come close to the jacks during the tensioning work. They focused on clearing the area during the tensioning work, resulting in higher safety.

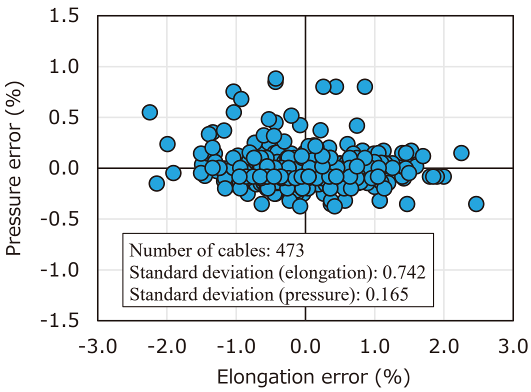

(a) Status near the pump
(b) Status near the jack

Photo 4. Status of automatic tensioning work

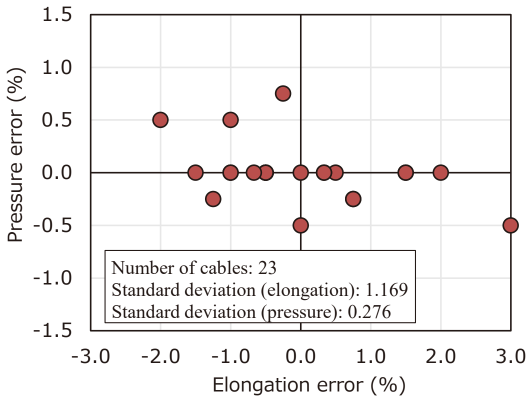
4-3 Accuracy improvement

Figure 9 illustrates the results of tension control using this system in construction of an actual PC structure (composite bridge) and compares them obtained using the conventional method on a different PC bridge of the same structure. The tension control was based on two indices: the pump pressure and the elongation amount of the prestressing steel strands. The error against the mean actual measurement values of each index was displayed in percentage (%) and plotted in the graph, and the magnitude of differences was evaluated based on the distribution. When this system was used, the standard deviation of elongation and pressure were 0.742 and 0.165, respectively.

When the conventional technique was used, the standard deviation of elongation and pressure were 1.169 and 0.276, respectively. The standard deviation of both indices was small when this system was used. Based on these results, use of this system is expected to improve the accuracy of tension control.



(a) Measurement results of the automatic tension control



(b) Measurement results of manual tensioning

Fig. 9. Comparison of distribution of measurement values

5. Conclusion

We developed a wireless automatic tension control system for prestressing steel strands, applied it in the construction of a PC bridge, and confirmed its effectiveness.

The wireless system eliminated the wiring work required for wired connection, contributing to reducing the labor required for the work. Automation achieved labor saving by cutting the number of workers required for the tensioning work from six to three. Safety and accuracy also improved.

6. Acknowledgment

We received tremendous cooperation from personnel of Nippon P.S Technologies Co., Ltd., who jointly developed this system, in terms of provision of information about tension control and implementation of the field test. We express our deepest appreciation.

Technical Terms

*1 Prestressed concrete (PC): Prestressing steel strands are used as the tensioning materials. The tensioning force is applied to compress concrete in advance (pre-stressing) to reduce the formation of cracks and their width. It is widely used for concrete structures, including roads, bridges, railroad bridges, cylindrical tanks, and building structures.

*2 Tensioning of prestressing steel strands: It refers to the work to apply tension to prestressing steel strands arranged in concrete using jacks. For example, general-purpose 28.6 mm prestressing steel strands that meet the JIS specifications require tensioning of about 74 tons. During the work, the tensioning force and elongation amount of the prestressing steel strands are measured to confirm that an appropriate prestressing force is applied.

*3 Anchorage part: It is a part to apply a compression force to concrete. It has the function to secure the prestressing steel strands subjected to tensioning using wedges (anchorage) and transmit the compression force of the prestressing steel strands to concrete.

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