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Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **55 (1987)**

PDF erstellt am: **29.04.2024**

Persistenter Link: https://doi.org/10.5169/seals-42742

Innovations in Construction Equipment, Machinery and System

Innovations dans les machines, équipements et systèmes de construction

Neuerungen von Bauausrüstung, Maschinen und Verfahren

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SUMMARY
This paper deals with the recent progress made in concrete construction technology in Japan. An intensified utilization of electronics and other leading technologies has led to the development of automated construction equipment/machinery, intelligent construction systems and sophisticated inspection techniques. Driving forces for the development are the needs in construction work to save labor, to enhance precision, to reduce time and cost, and to improve the working environment.

RÉSUMÉ
Cet article traite des récents progrès dans la technique de construction en béton au Japon. L'utilisation intense de l'électronique et d'autres technologies de pointe ont conduit au développement d'appareillages et de procédés de construction automatisés, de systèmes avancés de construction et de techniques de vérification sophistiquées. La nécessité d'économiser la main d'œuvre, d'augmenter la précision, de réduire la durée et le coût de construction, d'améliorer le milieu de travail, produit une force motrice favorable en vue de ce progrès.

ZUSAMMENFASSUNG
Dieser Bericht zeigt die neueste Entwicklung der Bautechnik in Japan. Die intensive Anwendung von Elektronik und anderen Spitzentechnologien führte zur Entwicklung von automatisierten Bauausrüstungen und zu computergesteuerten Bauverfahren mit einer hochentwickelten Qualitätskontrolle. Diese Entwicklung wurde gefördert durch die Notwendigkeit, Arbeitsplätze im Bauwesen zu erhalten, die Präzision zu erhöhen, Zeit und Kosten zu sparen sowie das Arbeitsklima zu verbessern.

1. INTRODUCTION

Recent advancement in electronics and robotics engineerings has enabled the manufacturers to realize extensive automation and robotization of industrial equipment and machinery. Following this advancement, vigorous and intensive efforts have been made in Japan to utilize the same frontier technologies in the field of construction.

Motivation of the efforts toward the construction innovation stems from the needs to save labor, to enhance quality and precision, to reduce time and cost, and to improve work environment. Labor saving in construction work becomes more and more important for the labor-intensive construction industry so as to cope with the shortage of skilled labor and the increase in number of workers at advanced ages. Recognition of importance to improve work environment also necessitates the development of construction robots, to which the hazardous tasks in harsh environment are to be assigned.

In the robotic applications to construction, peculiarities of construction operations such as fragmentation of projects into separate phases and uncertainty in weather and environmental factors make innovation more difficult than in other industries.

With the above technical and social background, several innovations in concrete construction have been made in Japan.

This paper gives an outline of the recent development in Japan's concrete construction technology regarding automation and robotization of construction equipment, machinery and systems. The paper will also refer to the possible further advancement of the concrete construction technology in the near future, to be expected to follow with progress in the computer hardware and software technology.

2. AUTOMATION/ROBOTIZATION OF CONSTRUCTION EQUIPMENT AND MACHINERY

2.1 General

In the field of construction, many types of automated equipment and machinery are successfully developed, some of which are called "robots." Basic technological issues concerning the development are sensing, mobility, control and system integration. The critical attributes of a robot are considered to be mobility, autonomy, capability to deal with large forces, and cognitive ability to cope with harsh environments.

Several successful examples are presented below.

2.2 Computerized Concrete Batching Plant

In order to provide high production rate, to meet diversified demand, and to efficiently control the quality of ready-mixed concrete, an effort to establish a computerized concrete batching plant is being made. Systematic operation of delivery trucks, batching, loading, testing and accounting is expected to be included in the plant system.

The new quality control system of ready-mixed concrete is linked with advanced instrumentations such as sensors for measuring surface water of aggregates, and water content and slump of fresh concrete.

2.3 Shotcreting Robot

Shotcreting has been widely used in Japan since 1975 corresponding to an increase in tunnel construction by the New Austrian Tunnelling Method (NATM).

Environmental condition of shotcreting in tunnelling is very poor mainly due to dust caused by rebounded materials and noise. To cope with this environmental

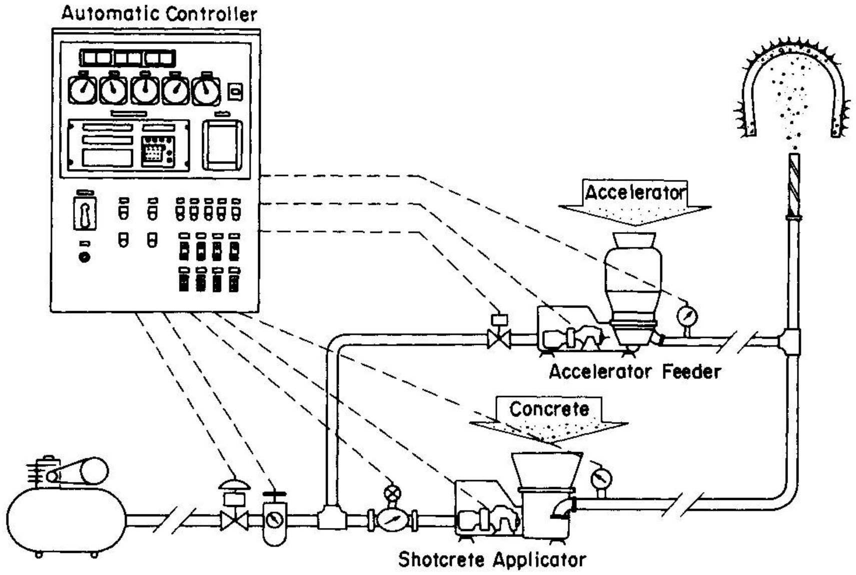

Fig. 1 Shotcreting control system

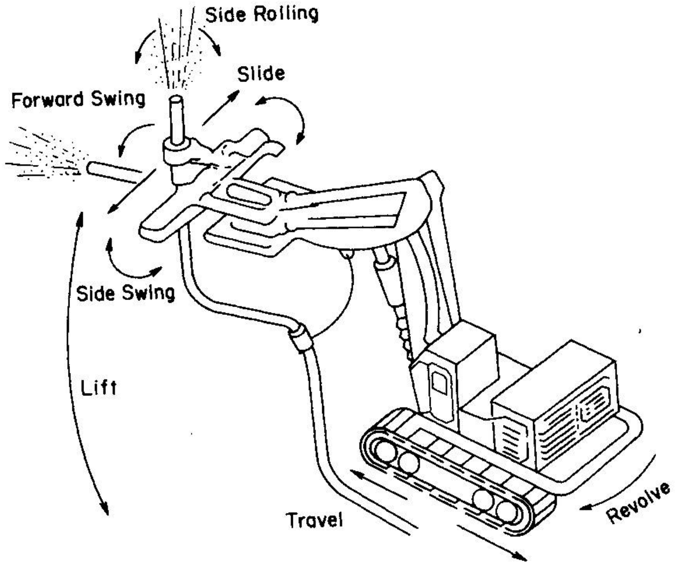

Fig. 2 Movement of shotcreting robot

problem and to secure construction efficiency, various types of shotcreting robots, or automated machines, have been developed and utilized in the NATM tunnelling or underground rock cavern construction.

Figs.1 and 2 illustrate an example of the automated shotcreting system for controlling quality and amount of concrete. Fig.3 shows a picture of the robotized shotcreting equipment of semi-automatic type. In Japan, more than 160 shotcreting robots of these kinds have been successfully put into practical use.

The requirements for securing quality and precision of shotcreting are as follows:

- nozzle should be positioned normal to the surface to be shotcreted,
- distance between nozzle and shotcreted surface should be maintained constant,
- moving rate of nozzle should also be as constant as possible.

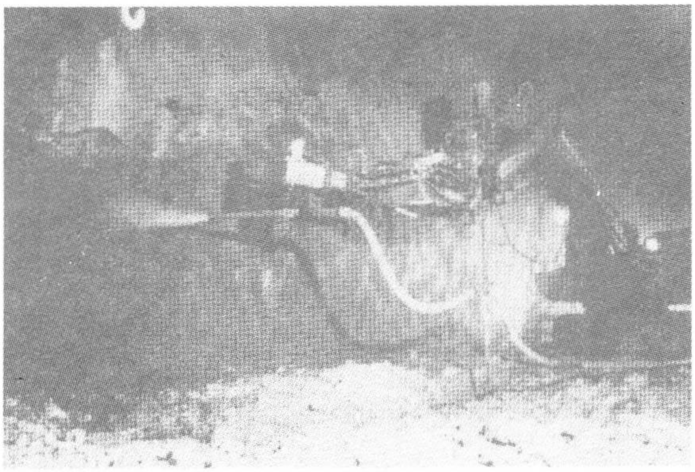

Fig. 3 Shotcreting robot

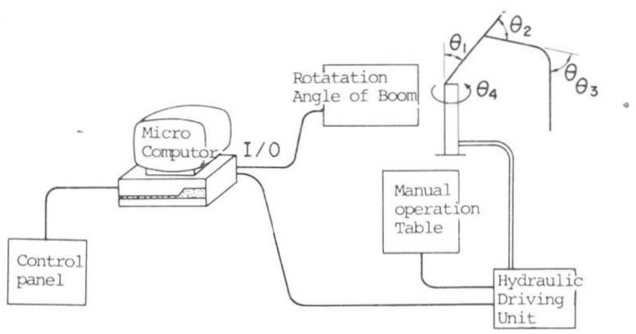

Fig. 4 Control system of concrete distributor

2.4 Concrete Distributor

Operation to move the flexible hose at the tip of piping in concrtete pumping and to change the piping layout is cumbersome and may impair the well-arranged reinforcing bars, resulting in degradation of quality of reinforced concrete construction. To cope with this inherent drawback of the concrete pumping method, a new concrete distributor has been developed.

Fig.4 shows an example of the automated concrete distributing system which is controlled by a microcomputor. With the system, concrete distribution to an adequate place is optimized at the most suitable intervals and rate. Movement of the articulated hose is controllrd by the microcomputer, and remotely-controlled vibrators are attached to the system. Use of the concrete distributor would impose minimal disturbance on the reinforcement.

2.5 Concrete Floor Finishing Robot

An optimum time for the finishing work differs depending on quality of concrete used and on an ambient temperature conditions. In some cases, the work has to be conducted at midnight. Furthermore, when finishing surface of concrete floors over a wide area, it may be difficult to secure the high flatness unless a number of very skilled trowelling workers are put in.

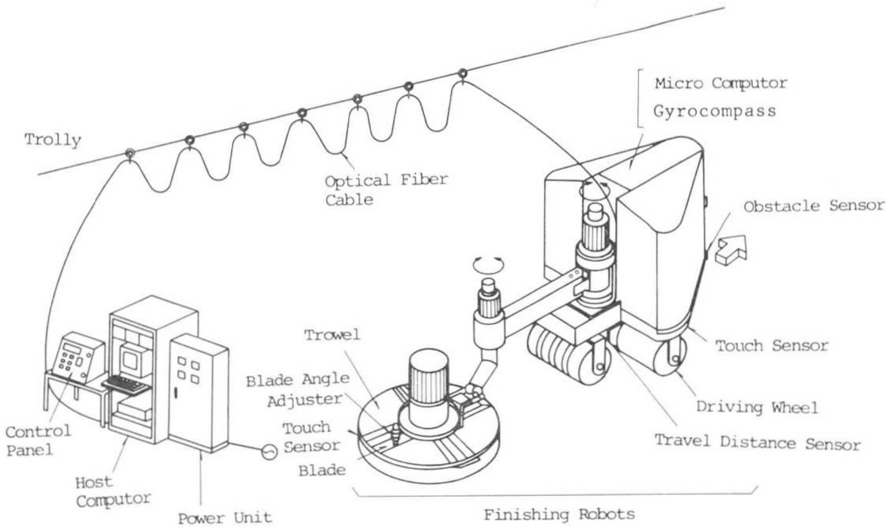

Fig. 5 System of floor surface finishing robot

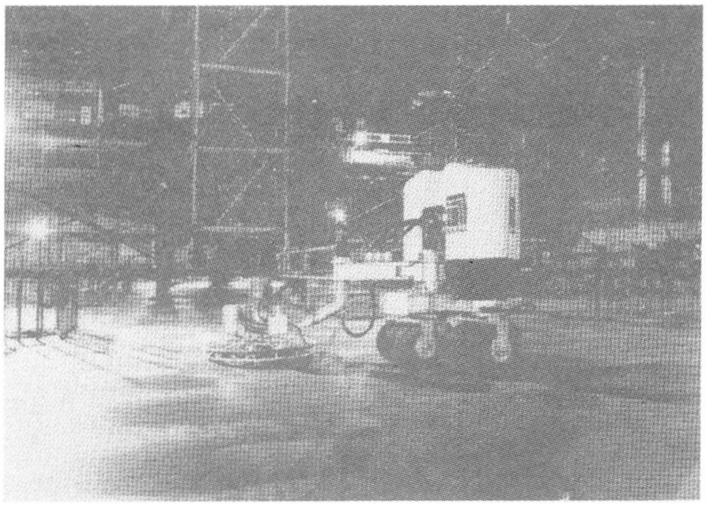

Fig. 6 Floor surface finishing robot

The necessity of development of concrete floor finishing robot thus stems from the needs to obtain a stable and high quality finishing, to save labor and to eliminate overnight work of the workers as much as possible.

Several floor finishing robots have been developed and successfully utilized in actual constructions. Fig.5 illustrates the system, and Fig.6 shows an example of surface finishing with the robot.

The robot is equipped with a travel distance sensor and a gyrocompass which enable the robot to perceive its own position and the flatness of finished surface. The robot is designed to be lightweight and provided with roller-type wheels for the work on soft concrete at a very early age. In the course of developing the robot, work standard on the surface finishing method and required flatness of finished surface has been established experimentally, upon which the operation criterion is based.

Experience obtained to date indicates that the quality of finished surface by the robot is as good as that by skilled labor, that operation is speeded up by

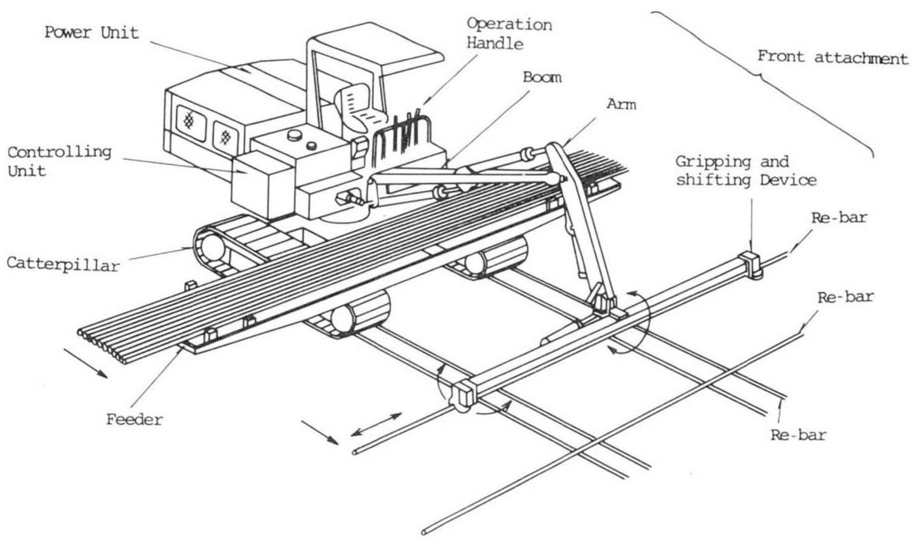

Fig. 7 Scheme of rebar arranging robot system

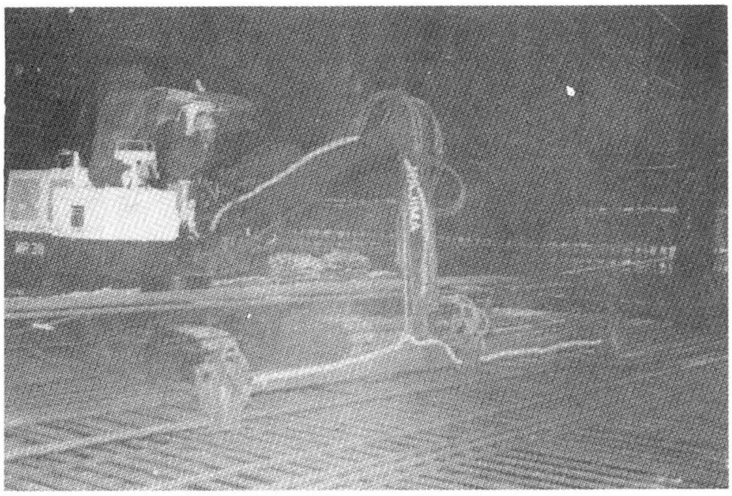

Fig. 8 Rebar arranging robot

50 % compared to troweling by manpower, and that manpower can be saved substantially.

2.6 Heavy Rebars Arranging Robot

In a construction project of the large scale structures such as nuclear power plant facilities, large-sized reinforcing bars up to D51 (nominal diameter: 51 mm) are frequently used. Arrangement work of such heavy reinforcing bars in a limited working space is very hard in terms of weight and quantity, and, in most cases, very time-consuming.

To cope with the above inconveniences, a rebar arranging robot has been developed. The schematic drawing of the robot is shown in Fig.7, and Fig.8 shows a picture of the robot in operation.

The robot, once installed in a predetermined position, puts reinforcing bars in

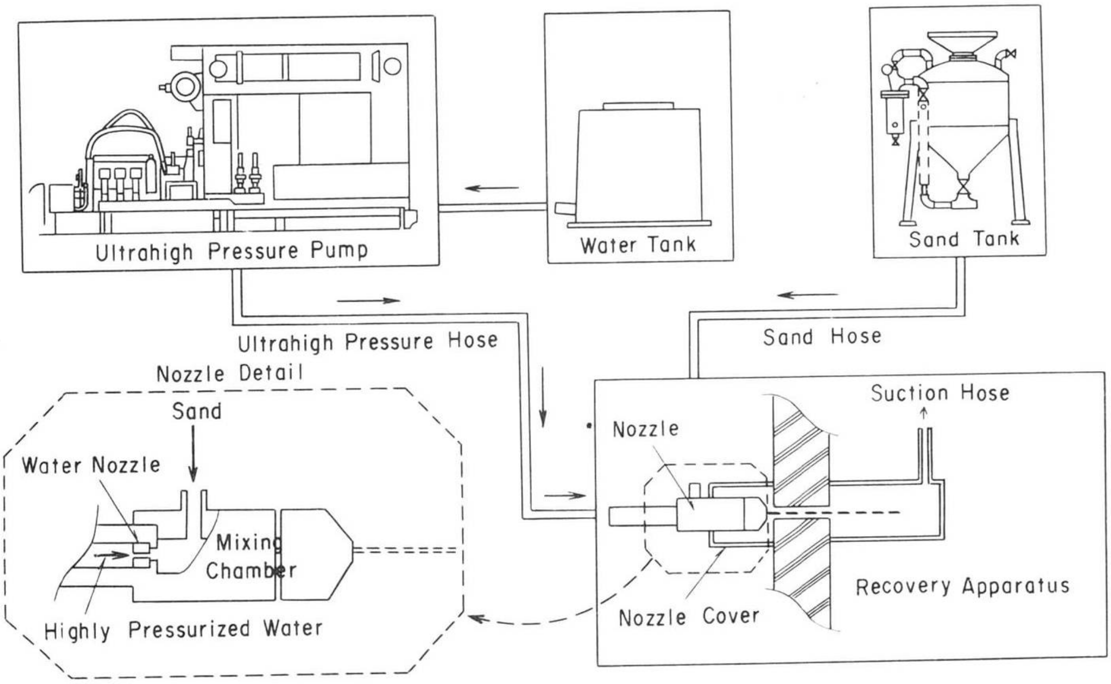

Fig. 9 Scheme of abrasive jet cutting system

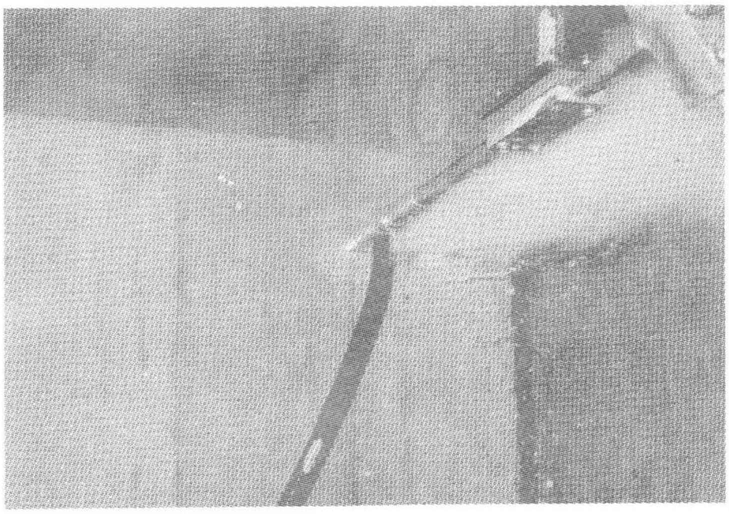

Fig. 10 Abrasive jet cutting system

a specified position at proper spacings. The spacing can be arbitrarily selected between 1 cm and 99 cm. Main body of the robot consists of engine, crawler, rebar feeder, and rebar handling device with controlling unit for positioning. In the actual application, either of manned operation or remotely-controlled operation can be chosen.

From an experience in a construction project of nuclear power plant facilities, in which D38 rebars with a length of 12 m each (100 kg/piece) were used, the following have been indicated.

- rebar arranging work can be carried out by the robot with good precision,
- labor-saving and speed-up of the work can be acomplished compared to the conventional method with a team of five to seven workers,

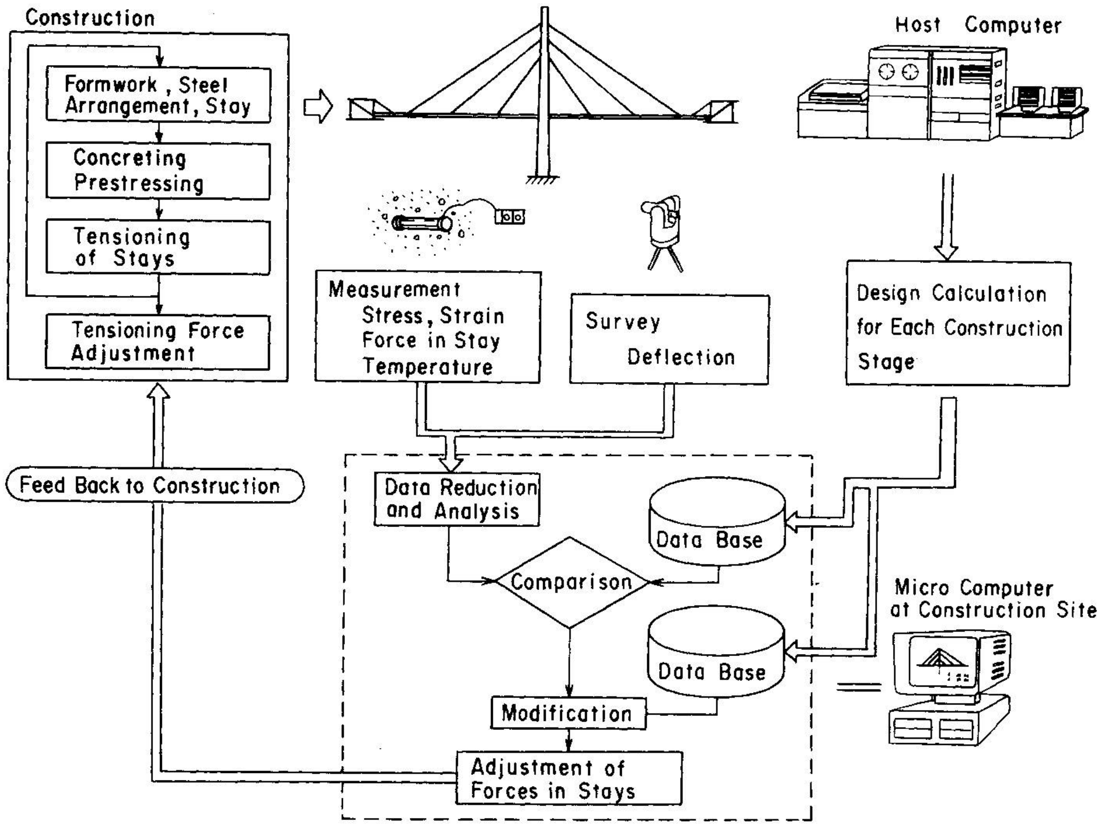

Fig. 11 Deflection control system for prestressed concrete cable-stayed bridges

- dangerous and hard work, especially for elderly workers, is eliminated.

2.7 Ultrahigh-Pressure Abrasive Jet Cutting Machine

As a tool of construction, reform and demolition of reinforced concrete structures, an advanced application of the conventional sand-blasting system to concrete cutting techniques has been realized. The schematic drawing of the ultrahigh-pressure abrasive jet cutting machine developed is shown in Fig.9. Fig.10 shows a picture of the machine in operation.

With the machine, concrete cutting operation can be done efficiently and speedily, and reinforced concrete members with depths of up to 150 cm can be cut without vibration problem and with noise being minimized. The pressure can be increased up to 250 MPa.

3. INTELLIGENT CONSTRUCTION SYSTEM

The basic idea of the intelligent construction system is to acquire data on construction timely, to reduce and analyze them promptly, and to reflect the obtained information, including results of the analysis, to the ongoing construction. Such system will rationalize the control and management of construction practice and will also pay off in the economics of construction. Needless to say, the intelligent systems of such kind are realized by the use of computer hardware and software technology.

Examples of the intelligent construction system are as follows:

- slip forming with online data desplay,

- high-precision ultradeep slurry wall excavation system for the construction of inground reinforced concrete diaphragm walls,
- sinking operation of large-diameter concrete caissons for the side walls of LNG inground reinforced concrete tanks,
- surveying and geometry-controlling system of the prestressed concrete bridge during construction, which is illustrated in Fig.11.

4. FUTURE DEVELOPMENT

4.1 Further Advancement of Robotization

The attempts made to date in Japan to utilize robotics engineering in concrete construction technology represent the first step of developing the various construction robots into more mature technology. In applying robotics to concrete construction, rather simple problems have been chosen in expectation that increased sophistication of the prototypes will follow as experience is gained. In other words, the current construction robotics are regarded to be in an embryonic state.

Many aspects of robotic-based construction shall differ from conventional construction technology, and there will be a fundamental rethinking of the entire design process of concrete construction as robots move into the workplace more and more. Economic feasibility is also important because of the amount of money involved to conduct the research and development.

4.2 Direction of Future Development

Robotics-related needs for the future development include: continuous sophistication of indicators and sensors; and integration of project data bases on design and construction. Research on artificial intelligence and laser beam will also be a matter of great interest.

Robotization of transportation, placement and compaction of concrete is foreseen, noticing that placing and compacting of concrete in the present concrete practice depend largely on experience of skilled labor.

It is also safe to say that robotics engineering will certainly play a key role in dismantling of aged nuclear power plants. Thus, the more sophisticated autonomous robots will be developed and extensively used in a harsh work environment.

4.3 Impact of New Materials

Development of new materials often results in realization of the new types of structures and construction methods, and will probably enhance innovation in concrete construction technology.

Among such new materials are:

- carbon fiber and aramid fiber which have been used in a form of fiber reinforced concrete, and now are considered to be used in a form of rods as a promising reinforcement for the concrete structures that never rusts.
- anti-washout concrete, or a specially developed underwater concrete named "Hydrocrete," which is to replace the conventional preplaced-aggregate concrete, and on which a great deal of research and development have been carried out.
- roller compacted concrete (RCC), or "Rollcrete," which greatly facilitated the construction of the gravity-type dams, and on which the innovative development is still actively being under way, especially for its application to concrete pavement.

5. CONCLUSIONS

The present status of innovation in concrete technology in Japan has been presented with respect to utilization of robotics and automated equipment.

Robotics utilization in construction has just begun, and a number of more successful applications are expected to come, bringing about a great advance in construction which results in higher quality and better performance of construction activities.

The Japanese construction companies as well as the public sector are significantly involved in the cultivation of further developments in robotic technology, and extensive corporate-funded R&D efforts have been made to devise innovative equipment. A Japanese government-sponsored research project has also been underway for these few years to develop robotics equipment for the most difficult of tasks such as maintenance and inspection chores in nuclear-power reactors and high-pressure work undersea.

With the experience in applied utilization of the automated machines already developed, the robotics technology in the construction field will be continuously fostered, noting the following:

- technological advancement is an important means for the construction industry to meet challenges of increased cost-effectiveness and improved competitiveness.
- technological advancement will provide significant new incentives for innovation and technologically based competition in the construction industry.

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