AN AUTOMATED SYSTEM FOR CONCRETING IN BUILDING SITES
—DEVELOPMENT OF AUTOMATED CONSOLIDATION SUBSYSTEM—

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ABSTRACT

An "Automated Consolidation Subsystem" has been developed as part of an effort to establish an integrated structure for mechanization and automation of concrete work of Ohbayashi Corporation. This system consists of performing the necessary vibration consolidation by automatically detecting from outside forms the level of concrete that has been placed. The results of consolidation remain in the form of records and can be utilized as a data base. As a result of trial application at an actual construction site, it was succeeded in simplifying consolidation operations, and skilled workers became unnecessary. Unconsolidated parts and non-uniformity were eliminated, contributing to an improvement in the overall quality of concrete placed.

1. INTRODUCTION

In building projects in Japan it is customary for concrete of columns, walls, beams, floor slabs, and stairs to be placed monolithically in one operation. At the same time, the cross-sectional configurations of these are mostly slender, while large amounts of reinforcing steel are contained. Accordingly, in filling and consolidating concrete in vertical members such as columns and walls, the situation has become such that the conventional rod-type vibrators cannot be easily used. Consolidation or tamping operations accompanying placement of concrete are performed in a congested condition where many workers are intermingled over a large area of the construction site. Consequently, it is difficult for control to be exercised, and problems such as unconsolidated parts and non-uniformity can easily arise. It was with such a background that an "Automated Consolidation Subsystem" was developed applying form vibrators that can be used from the exteriors of forms.

This automated subsystem for consolidation developed was intended for an integrated structure of mechanization and automation of concreting work of Ohbayashi Corporation, and follows the earlier Placing Crane (distributor for concrete pump), Autobucket (bottom-dump bucket with automatic discharge), and Floor Work Robot (concrete floor surface finisher).

This report mainly takes up the automated subsystem for consolidation and the format for assuring concrete quality, together with wich an outline is given of the various component technologies comprising

the integrated structure for concreting works.

2. INTEGRATED PLAN FOR AUTOMATION OF VARIOUS CONCRETING PROJECTS IN COMPANY

Concrete work generally consists of a procedure beginning with issuing an order to a ready-mixed concrete plant and ending with curing of the concrete. During this time, the main operations of the constructor are fabricating and assembling of reinforcing steel and forms, conveying within the premises of the job site (conveying by concrete pump or bucket), placing, consolidating, finishing, curing, and quality control and inspection at the various stages of work. Of these, the operations with regard to conveying, placing, consolidating, and finishing carried out on the day of placement are of special importance, and the outcomes of these will determine the quality of the structure.

Ohbayashi Corporation has been making efforts to mechanize and automate these important operations and has developed and put into practical use such items as a Placing Crane (conveying, placing), Autobucket (conveying, placing), and Floor Work Robot (finishing). Consolidation remaining to be mechanized and automated involved factors unsuited to automation because of the complex behaviors of fresh concrete itself, in addition to which, it was an aspect depending to a great extent on the "feel" and experience of skilled workers. The development of the Automated Consolidation Subsystem has added an impetus to the company's integrated plan for automation of concreting work and has brought to completion the overall concept. The various subsystems which are the other component elements of the automation system are introduced in this section.

(1) Placing Crane (Photo. 1)

The Placing Crane is an "automatically controlled placing crane" having the composite functions of a concrete distributor and a crane. There is a boom possessing four joints and one rotating seat, and the movements of these are controlled by computer. The nozzle of the concrete pipeline finds easy access to any placement point on the floor with a joy stick manipulated by the operator. Through development of this subsystem, it was made possible for work to be done without reinforcement placed on the floor slab form being disturbed by the flexible hose at the end of the pipeline, added to which placing efficiency was improved and work steps reduced in number. Further, through the addition of crane functions, favorable results such as high rate of operation and no changes in pumpability and concrete quality were obtained.

(2) Autobucket (Photo. 2)

The Autobucket is a type of bottom-dump bucket, the discharge gate of which can be opened and closed by an operator on the ground through remote control by radio. The volume of concrete that can be held is 2.5 m^3, and the structure is such that concrete can be received directly from a truck agitator. The development of this subsystem has made possible assurance of safety at high locations.

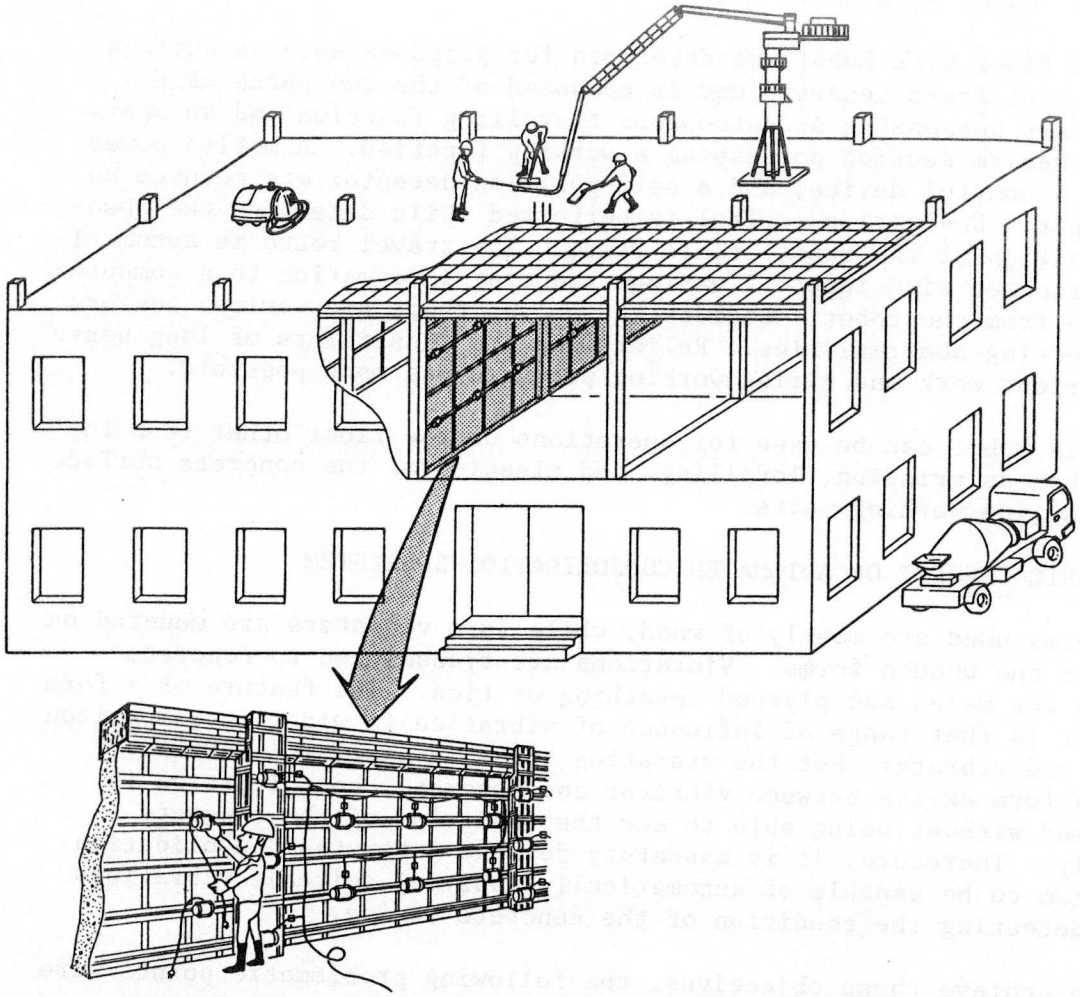

Fig.1 Conceptual Drawing of Integrated Automated System for Various Concreting Projects

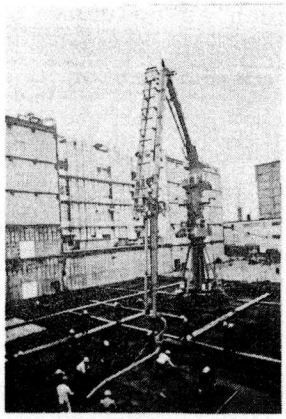

Photo.1 Placing Crane

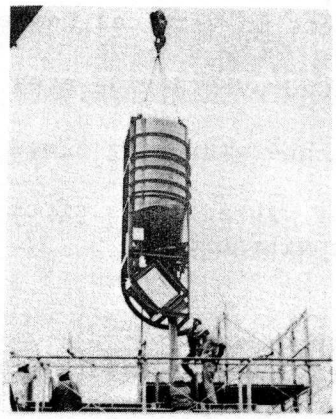

Photo.2 Autobucket

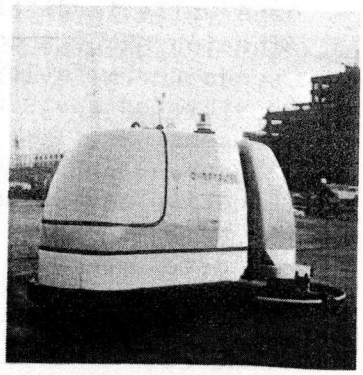

Photo.3 Floor Work Robot

(3) Floor Work Robot (Photo. 3)

The Floor Work Robot was developed for purposes such as surface finishing of fresh concrete and is composed of the two parts of a mobile cart possessing an autonomous travelling function and an operation mechanism section possessing a working function. A motive power source, a control device, and a self-position detector are mounted on this robot. Navigation control is performed while detecting the absolute location of the robot at all times. The travel route is automatically prepared with input of various kinds of information to a computer separate from the robot. Besides the above, there are various sensors for detecting abnormalities. Relief from the constraints of long hours of laborious work and tiring working postures was made possible.

This robot can be used for operations on the floor other than the above such as grinding, levelling, and cleaning of the concrete surface by exchanging working parts.

3. BASIC CONCEPT OF AUTOMATED CONSOLIDATION SUBSYSTEM

Forms used are mostly of wood, while form vibrators are mounted on wales of the wooden forms. Vibrations are transmitted to concrete through the wales and plywood sheathing or ties. The feature of a form vibrator is that range of influence of vibration is wider in comparison with a rod vibrator, but the vibration force is smaller. Further, since a form exists between vibrator and concrete, consolidation is performed without being able to see the condition of the concrete directly. Therefore, it is mandatory for the Automated Consolidation Subsystem to be capable of automatically applying suitable vibrations while detecting the condition of the concrete inside.

To achieve these objectives, the following problematic points were analyzed while development was done with the aims listed below.

Problematic points:

(1) Workers engaged in placement are overly concentrated at the nozzle of the pipeline.
(2) Consolidation of concrete in vertical members such as columns and walls is difficult.
(3) The job site is congested over a wide area and communication tends to be faulty.
(4) Unvibrated spots occur and vibrating times tend to be inconsistent.
(5) The necessary amount of vibration is often not applied to the location requiring the vibration.

Aims of development:

(1) Improvement in concrete quality
(2) Improvement in productivity (simplification of operations, reduction in skilled work, improvement in working efficiency)
(3) Relief from adverse work environment
(4) Relief from hazardous work

The composition of the apparatus of this system is as follows:

(1) Vibration (form vibrator)
(2) Detection (concrete level sensor)
(3) Control (multiplex transmission device, acceleration sensor, concrete placement volume sensor, microprocessor)
(4) Supervision (personal computer)

4. DETAILS OF AUTOMATED CONSOLIDATION SUBSYSTEM

4.1 Features of Subsystem

This subsystem is such that when concrete is placed inside a form, concrete level sensors attached to the form react and vibrators are activated. The vibrators continue working until the amount of vibration required for consolidation of concrete has been achieved. Stopping of action is done by a command from the supervision computer according to a timer (adjusted for required time interval) or based on information from acceleration meters set on the vibrators.

4.2 Composition and Specifications of Subsystem

The outline of the subsystem, as shown in Fig. 2 and Photo. 4, includes form vibrators, concrete level sensors (Photo. 5), a multiplex transmission device, a controller, and supervision computer, and cords and cables interconnecting these items. The subsystem has 10 form vibrators to a unit and up to 3 units, or 30 vibrators, can be handled. In principle, the system is designed predicated on form vibrators being reset one unit at a time in the direction of placement, but it is permissible for a unit to be subdivided. An outline of the subsystem specifications is given in Talble 1, and a block diagram of the subsystem is shown in Fig. 3.

Sensors play important roles in the subsystem. Especially, the concrete level sensors are sensitive only to the alkali of concrete, and the vibrators will not be erroneously activated by such things as water sprinkled in forms prior to concrete placement. The sensors are in the form of nails and can be attached to or detached from form sheathing using clawed hammers, and moreover, can be reused elsewhere.

4.3 Interaction with Concrete Quality Assurance Setup

It is possible for data of the items below to be collected as records of the state of consolidation, and for these to be graphically expressed in real time (PHoto. 6).

Consolidation location (indicated on plan, elevation)
Vibration time (starting and finishing times of consolidation recorded on 24-hour basis)
Vibrating force (expressed in terms of product of acceleration and consolidation time)
Placement volume (automatic recording of data on volume of concrete pumped)

It is set up so that these data would be incorporated into the quality assurance system of the company for effective utilization.

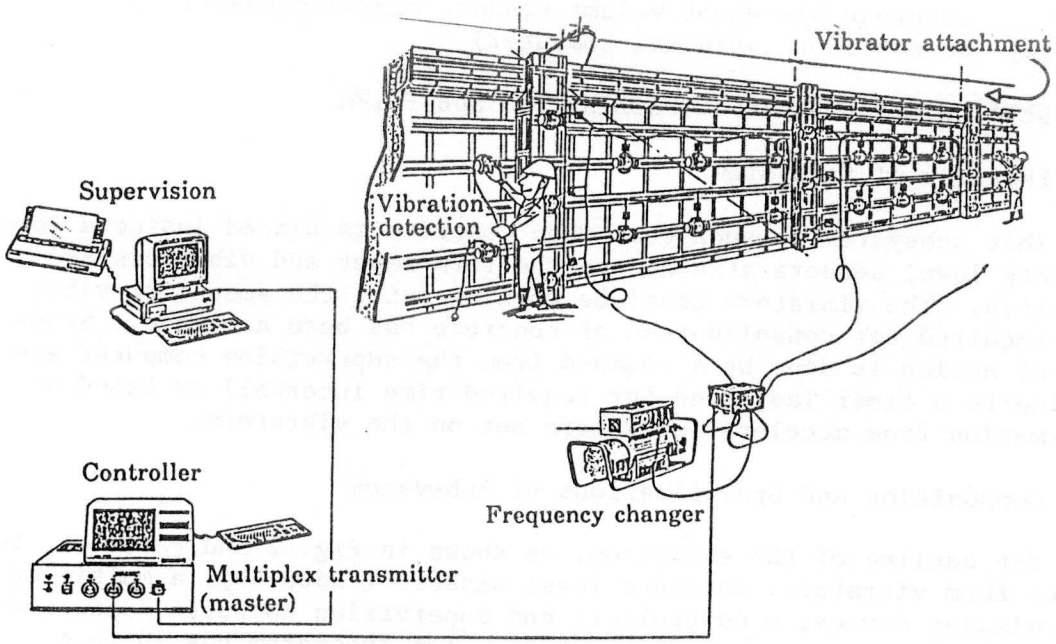

Fig.2 Outline of Subsystem

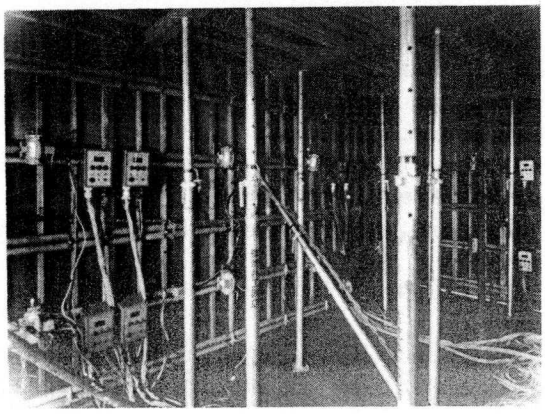

Photo.4 View of Vibrators
Attached at Bullding Site

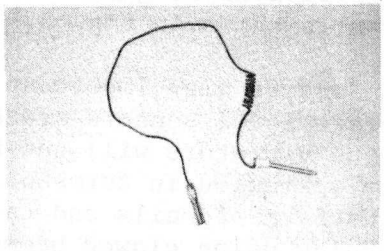

Photo.5 Concrete Level Sensor

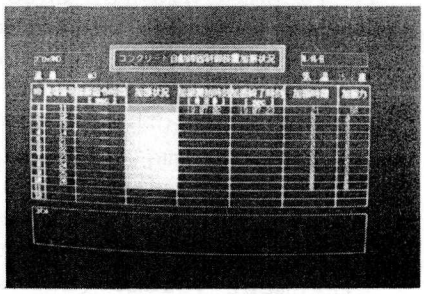

Photo.6 Example of Display
(Vibration Results)

Table 1 Principal Specifications of Automated Consolidation Sybsystem

Function	Eguipment Used	Specifications
Vibration	Form vibrator	AC 43 V,200/240Hz,250kg,100kg
Detection	Concrete level sensor	Galvanized steel nail (length 25-30mm)
	Amplifier	Isolated amp, comparator
Control	Multiplex transmission device	Frequency discrimination system, Model UTD-2560, (64 channels)
	Acceleration sensor	Strain gauge type acceleration meter, strain meter, comparator
	Concrete placement volume sensor	Microwave proximity switch
	Microprocessor	CPU 8086×2 (PC9801VM2 eguivalent,RAM 640KB)
Supervision	Personal computer	CPU 8086×2 (PC9801VX41:HDD·20MB), CPU 8086

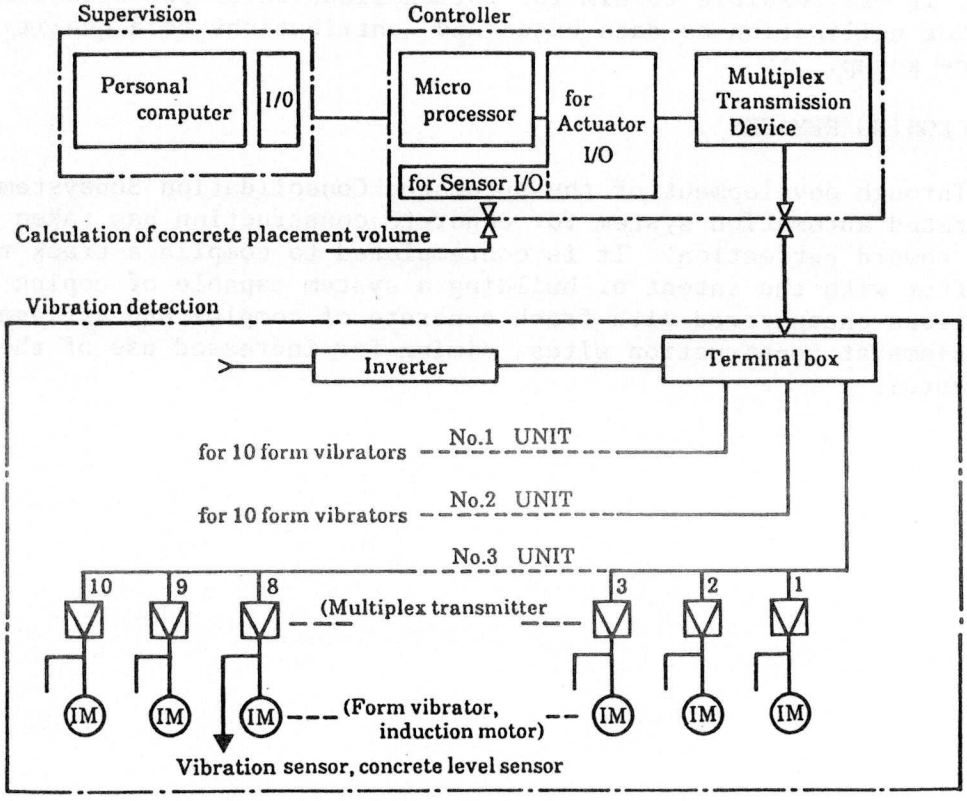

Fig.3 Automated Concrete Consolidation Apparatus Block Diagram

4.4 Precautions in Utilization of the Subsystem

In utilization of this subsystem, the performance required of vibrators, condition of propagation of vibrations produced by vibrators, vibration acceleration and frequency required for consolidation by vibration, vibration time, etc. for supervision of concreting are necessary, and investigations were made of them in a separate study.

5. EVALUATION OF SUBSYSTEM THROUGH APPLICATION IN ACTUAL PROJECTS

As a result of application of this subsystem at several building sites, it was found to be effective for consolidation of concrete in column or wall members where it was difficult to use internal rod vibrators. In particular, it was succeeded in reducing the number of workers assigned to the pipeline nozzle and to form tapping by approximately 50 percent. Overall, there was a reduction of about 30 percent in personnel. A prominent effect was that skilled workers became unnecessary since it was succeeded in simplifying work through automation. Furthermore, unconsolidated spots and non-uniformity were eliminated. The results of consolidation were preserved in records, and by comparisons with the condition of the finished concrete on stripping of forms, it was possible to aim for rationalization of consolidation and also for utilization as data bases and contributions to a quality assurance setup.

6. CLOSING REMARKS

Through development of the Automated Consolidation Subsystem, the integrated automation system for concrete construction has taken sure steps toward perfection. It is contemplated to compile a track record hereafter with the intent of building a system capable of coping with situations encountered with fresh concrete of complex and variegated mechanisms at construction sites, aiming for increased use of the overall system.