Development of a Concrete Screeding Robot

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Abstract

This paper describes the characteristics of a newly developed concrete screeding robot and the results of fundamental experiments conducted. There were four principal aims of this development: 1) to improve on screeding working conditions over conventional methods; 2) to increase productivity; 3) to assure the quality of concrete floors; and 4) to establish a system of concrete work capable of being performed by robots.

The concrete screeding robot consists of a screeding component, a traveling component, and a controller. The robot travels on reinforced steel bars and screeds the concrete surface using a screeding device which receives a laser beam emitted from a rotating laser transmitter. The concrete screeding robot is expected to increase the productivity of concrete floor work in combination with the concrete floor finishing robot to be further developed in the future.

1. Introduction

Many problems continue to be inherent in construction work such as dangerous as well as hard physical work, low productivity, the shortage of workers, and aging of expert workers. Among various kinds of construction work, concrete work remains one of the most common and important processes on almost every construction site. Importanty, however, concrete work is a labor-intensive job requiring considerable physical effort. Therefore, it is strongly desirable to automate and robotize concrete floor work including the leveling and screeding operations.

In the past several years, concrete floor finishing robots have been developed by Japanese general contractors for concrete floor work, and the areas of their aplication have been increasing steadily. However, since these robots are only applied to the floor finishing step, which is the latter half of concrete floor work, they do not sufficiently reduce manpower through out the entire concrete floor work steps. In line with this, we undertook to develop a screeding robot for facilitating the concrete leveling and screeding steps as the first half of concrete floor work.

2. Development background

In concrete floor work, the direct finishing method (monolithic method) is usually adopted in Japan. Generally, this method is performed by professional workers according to the work procedure outlined in Fig. 1. Satisfactory completion of each step in the procedure is dependent on the skill and experience of the workers involved. As a result, three principal problems remain:

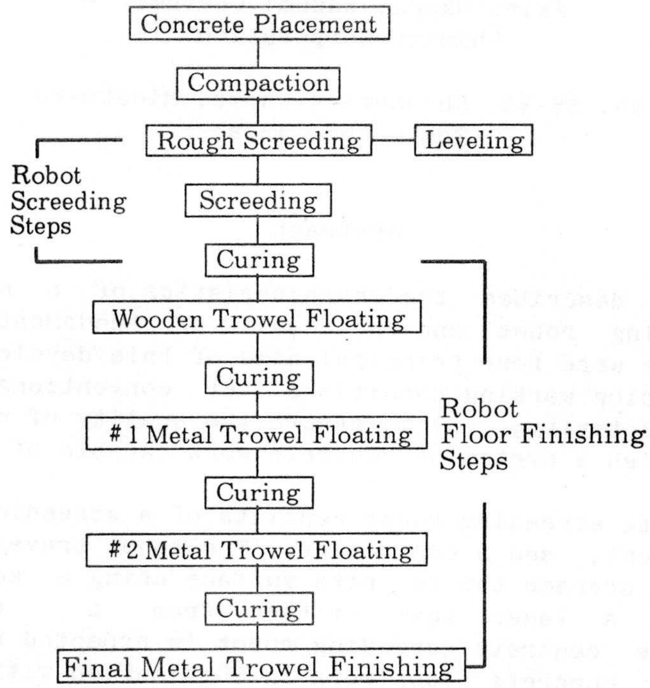

Fig.1 Standard Working Procedure

(1) The workers must work hard in a squatting position. (Photo 1)
(2) The quality of the finished concrete floor depends on the workers' skill.
(3) The overall quality (including the levelness) has shown a tendency to be lower because of the increasing shortage of skilled workers.

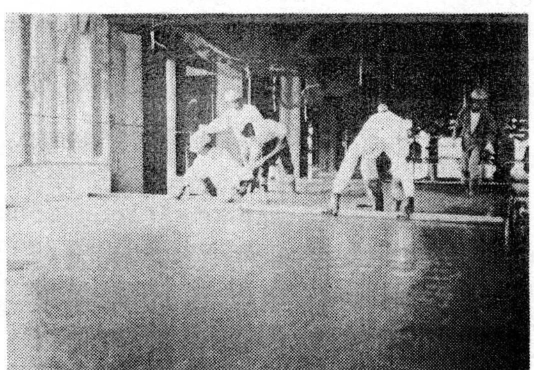

Photo 1 On–site screeding work

For the latter half of concrete floor work, the concrete floor finishing robot has witnessed increasing involvement. However, no robot has been developed yet for the leveling and screeding steps because considerable technical difficulties have remained to be solved. The present concrete floor work using the concrete floor finishing robot has remained unsatisfactory, though because manpower reduction has not been enough, and because workers have not been sufficiently relieved from their current working conditions and hard physical work.

In light of these problems, we undertook to develop a specific robot for the concrete leveling and screeding steps.

3. Development

The development of this robot involved three technical areas as briefly described below.

3.1 Preliminary research

Before setting out to develop the robot, we studied actual on-site screeding work. Our study led us to two important findings:

(1) The levelness standard of floors is between -5 mm - +7 mm.
(2) The concrete placing speed is approximately 100 m^2/hr on the average, increasing to 150 - 180 m^2/hr when concrete is placed only on floors slabs.

We thus set our concrete levelness and screeding capacity targets for the robot at $\pm$ 5 mm and 200 - 300 m^2/hr.

3.2 Inspection and experiments on the screeding method

We performed screeding board and screw auger experiments using a rail-type screeding device to determine which would better serve as a screeding tool. Four factors essential to the robot as a tool became apparent:

(1) When using a screeding board, screeded concrete is left in front of the board, and the tensile force is increased as the board is pulled (Photo 2).
(2) Since the screedng board scratches the coarse aggregate, the screeded surface is roughened.
(3) Concrete can be flattened and screeded with a screw auger (Photo 3).
(4) The coarse aggregate in the concrete is settled with a tamper.

Based on the results of the above inspection and experiments, we decided to combine the screw auger and tamper and use them together as the screeding tool.

3.3 Experiments on the traveling method and level adjusting mechanism

Considering the results of the inspection and experiments and through discussions with persons in charge of concrete placement and finishing, we determined the appropriate approach for the traveling

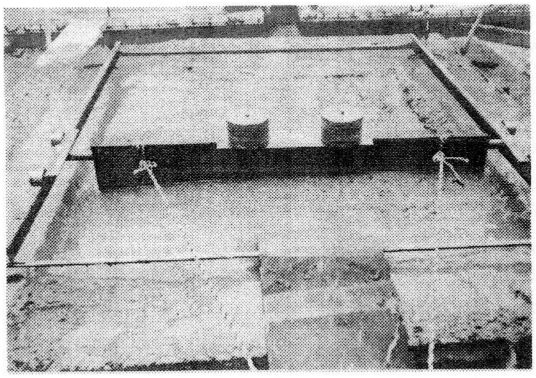

Photo 2 Screeding board experiment

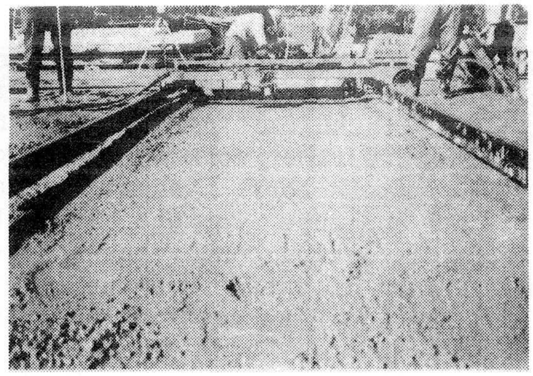

Photo 3 Screw auger experiment

and level adjusting mechanisms for the screeding robot. These focused on :

(1) Mounting the robot on wheels and moving it on reinforced steel bars; minimizing the width of each wheel so that it does not make deep ruts in the concrete.
(2) Installing stabilizers to stabilize the traveling and to disperse the weight.

Reevaluation of these values confirmed that wheels having an even surface could generate enough force to move the robot along the reinforced steel bars.

In addition, we decided to install a level adjusting mechanism providing two functions:

(a) Sensing the level position using a rotating laser level and laser receivers.
(b) Adjusting the level by moving the screeding device up and down with motors and screws enabling the laser light to be received at the center of the laser receivers.

Since the response of the level adjusting mechanism affected the screeding accuracy, we performed experiments using the experimental equipment detailed in Fig. 2 to confirm this response.

This experimental equipment incorporated a simulated level adjusting mechanism facilitating the up and down movement of the screeding device.

Figure 3 shows the partial results of the screeding device operation.

The results of the above experiments demonstrated that the level adjusting mechanism had a satisfactory response and that it could assure sufficient screeding accuracy. In particular, when the detecting accuracy of the laser receiver was coarse , the difference between the maximum and minimum screeded levels was not more than 5 - 7 mm, and when the detecting accuracy was fine , it was 2.5 - 3 mm. Furthermore,the response of the screeding mechanism at a 600 r.p.m. laser transmitting speed was higher than that at 300 r.p.m. Accordingly, a smoother floor could be obtained at 600 r.p.m.

We manufactured a trial machine based on all considerations, and completed its fabrication by partially modifying the traveling and screeding devices.

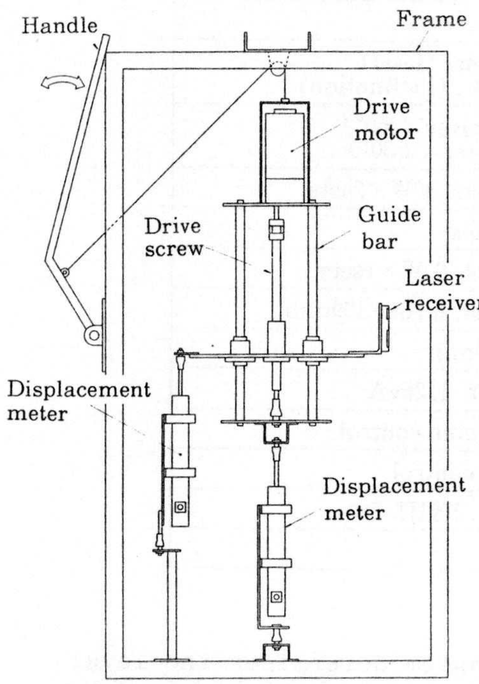

Fig.2 Experimental equipment
(Level adjusting mechanism)

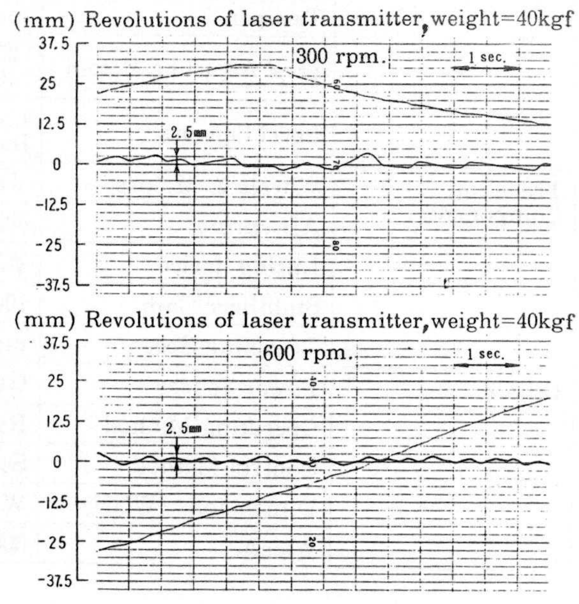

Fig.3 Experimental results
(Level adjusting mechanism)

4. Robot Configuration

The concrete floor screeding robot is roughly divided into a screeding component, a traveling component, which can be separated if necessary, and a controller. It travels on reinforced steel bars and screeds the concrete with the screeding component while receiving laser input from the rotary laser level transmitter.

The power source and controller are mounted together on the traveling component enabling the entire mechanism to move automatically.

The main specifications of the trial machine are given in Table 1. The components of the concrete screeding robot are shown in Fig. 4.

4.1 Screeding component

The screeding component consists of the main auger screw, sub-auger screw, tamper, level and inclination adjustment mechanism, and drive motors. The level and inclination adjusting mechanism includes right and left laser receivers, inclinometer and drive devices. The main and sub-augers, which are rotated by motors, scrape the concrete or move it sideways, then tamp the concrete surface with the tamper to settle the course aggregate in to the concrete.

Table 1 Specifications of Concrete Screeding Robot

Screeding Component	Main Auger motors	120W×2sets, max. 120r.p.m.
	Sub Auger motors	60W×2sets, max. 120r.p.m.
	Tamper	max. 5rev./sec.
	Level Adjusting Motors	25W×2sets, (level) 40W×1set, (inclination)
	Level Sensors	Laser receiver (360°) Inclinometer (±30°)
Traveling Component	Wheels & Motors	φ800×2sets, 80W×2sets
	Air spring	40kgf×2sets
	Lifting device	φ500×1set, 60W×1sets
	Stabilizer Cam	100W×1set, stroke 100mm
	Traveling Speed	max. 6m/min.
Others	Power Source	Generator 1.2kvA
	Operating Method	Radio remote control
	Control Method	Sequence control
	Dimensions (WLH)	W1.5×L1.7×H1.2m
	Weight	300kgf

The level and inclination adjustment mechanism determines the level of the floor to be screeded. The drive devices, which are supported by the traveling component, move the augers and tamper up, down, and right and left to the set level of the concrete floor.

Laser receivers having a receiving angle of 360° (detection accuracy: ±1 mm) were used in this trial machine.

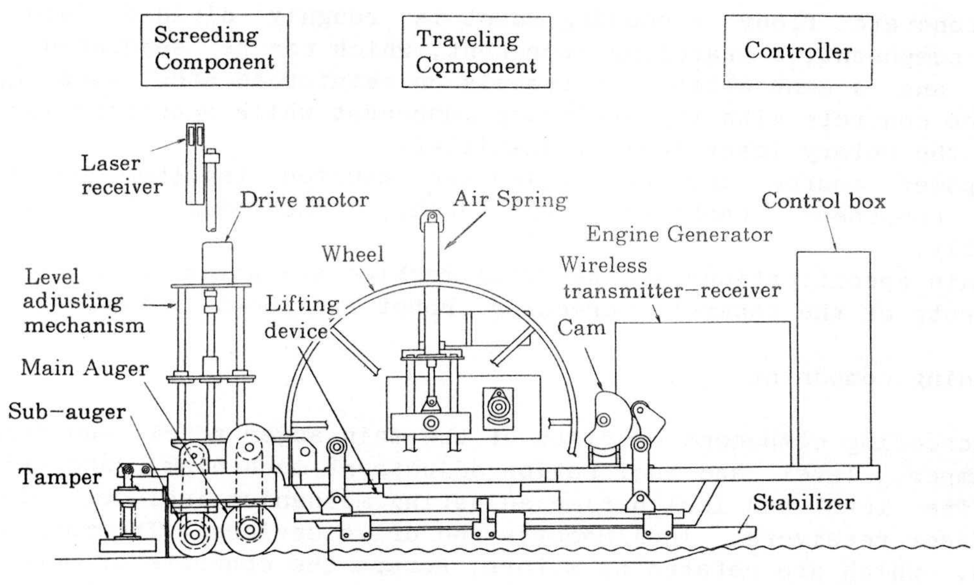

Fig.4 Components of the Concrete Screeding Robot

4.2 Traveling component

The traveling component is composed of the wheels, air springs for pushing the wheels on the reinforced steel bars, frame, stabilizers, cams for driving the stabilizers, lifting device for changing the travel direction, and the drive motors. The right and left wheels are driven by their respective motors to move the entire mechanism over the reinforced steel bars.

The four stabilizers are installed on the lower part of the frame to stabilize the travel and reduce the traveling resistance. They also evenly disperse the weight of the robot.

The stabilizers are equipped with roller-type guides. They are moved forward on orders from the cams for driving the stabilizers. The frame is subsequently slid ahead by the propelling force of the wheels over the reinforced bars on the stabilizer guides.

When the travel direction is changed greatly, the lifting device is lowered, where it is supported by the reinforcement bars, and the frame is lifted up. The wheels are then rotated in the directions opposite each other. The robot can be turned either clockwise or counterclockwise.

4.3 Controller

The controller is made up of the control panel (with a built-in sequence unit), power source (generator), and wireless transmitter-receiver, which is of the fixed sequence control type. Specifically, the screeding and traveling components are operated by wireless remote control according to a preset procedure. Accordingly, the robot must be assisted by an operator prior to and during the operation.

The screeding work currently being done has two significant problems.

(1) The conditions of floors, pillars, wall reinforcement bars, etc., of differ from one building to another, and screeding work must be performed while avoiding these obstacles. To screed the floors, highly accurate sensors in conjunction with judging and processing systems are required to detect obstacles and then to make the appropriate judgment and select the proper travel route. Developing such a system is presently very difficult.

(2) Considerable difficulty seems to remain for a robot, depending on its dimensions and shapes, to screed internal angles, external angles, parts near walls, and so on. The blank spaces left by the robot must be accordingly screeded by hand as before.

For these reasons, we designed the control system so that the screeding conditions could be judged visually, and so that the action that needs to be taken can be judged by the operator.

5. Trial Robot Performance Results

Through a series of experiments, we confirmed the performance capabilities of the trial concrete screeding robot. For the experiments, we placed ready mixed concrete (slump: 19 cm) on reinforced bars (mesh bars:D10 x @150), then screeded it with the trial robot.

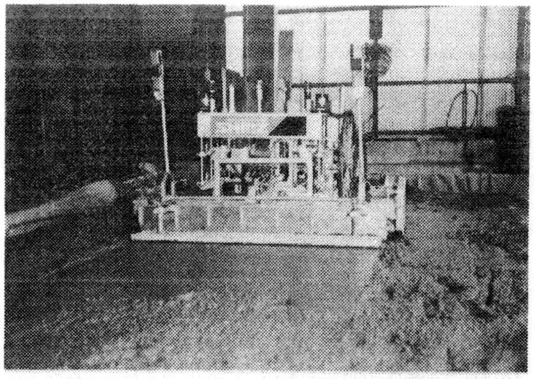

Photo 4 Screeding robot experiment

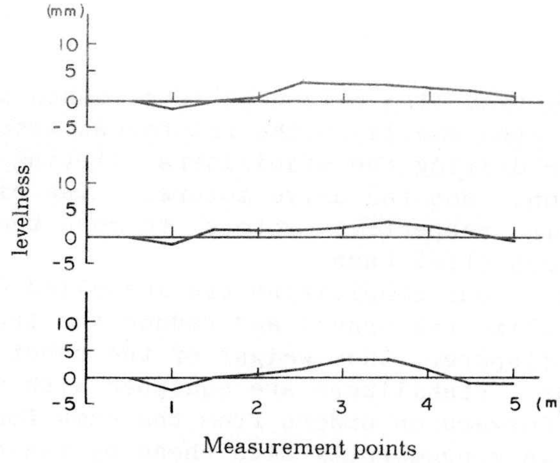

Fig.5 Experimental results of screeding robot

The experiment up set is shown in Photo 4. Typical experimental results (level of the screeded floor) are shown in Fig. 5. As is evident, the level is within the target range of ±5 mm. Overall the results were generally good for the experimental stage.

6. Feature Research

We plan to use the data on the trial robot to perform further experiments to obtain additional data concerning the following points.

(1) Mechanical capacity (specifically, limit values) of the screeding and traveling.
(2) Effects of the characteristic difference in concrete (specifically, slump) on the screeding work and on screeding accuracy.
(3) Length of time required after concrete is placed before its surface can be screeded.
(4) Accuracy of screeding area overlapping.
(5) Effects of the arrangement of reinforcement bars (diameter and pitch of the reinforcing bars) on screeding.
(6) Improvement of operating procedure and maintenance.
(7) Comparison between the screeding accuracy of a human and that of a robot.

7. Conclusion

This paper has described the background and history of the development, configuration, and performance results of a concrete screeding robot. It sould be stressed that we are still in the initial stages of development, with many problems remaining to be solved. Development will continue to progress quilkly, however, in an effort to improve the current working environment and labor conditions. Once developed, we hope to incorporate the robot into a total concrete floor system for wide application to concrete placement and finishing.

We are very grateful to all persons who have cooperated with us in this robot research and development and in the concrete screeding robot experiments.