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An Automatic Vibrating Roller Operation System

Koichi Utsuka
Yoshio Kurihara
Miyagase Dam Construction Office
Ministry of Construction (Japan)

Masao Fujiwara
Mitsubishi Heavy Industries, Ltd.

ABSTRACT

Compacting the spread concrete with a self-powered vibrating roller is an essential feature of the RCD (Roller Compacted Dam-concrete) method of constructing a concrete gravity dam. It is an arduous task for the roller operator to remain seated on the roller not only because the working area is unusually extensive and wide, but also because he has to keep on repeating the same compacting cycle pattern. The number of compacting cycles, moreover, must be rigidly controlled to produce the required concrete quality.

The automatic operation system introduced here operates the roller automatically and adjusts the number of compacting cycles under computerized control. This paper describes the system, its basic principle, the process of its development, and its current problems to be solved.

1. INTRODUCTION

(1) Construction of Dams by RCD Method

The technology of modern concrete dam construction finds its basis in the 1936 commissioning of Hoover Dam, which was built by the columnar block method of construction (illustrated in Fig. 1. Column method of execution). During and after the 1950s, the techniques of dam engineering advanced rapidly, giving rise to two new concepts, concrete-arch dam and hollow-concrete gravity dam, both aiming at reducing the structural volume of embankment to achieve a substantial cost reduction.

In Japan the national economy kept expanding during the 1970s, but this period of rapid growth was followed by stable growth while the cost of basic materials. In the area of dam construction, cost saving had to be sought not so much in dam volume reduction as in more intensive mechanization of dam construction work. Handle the materials in greater mass to cut down the per-unit cost of concrete, thereby making up for the rise in labor and other costs: this was the dictate of the times. It was in response to this need that the RCD method, mentioned above, was developed in Japan.

This RCD method was intended to adapt the all-layer method, a method till then used in building rock-fill dams, to the construction of concrete gravity dams. (See Fig. 2. Layer method of execution.) The reason of this adaptation is chiefly this: rock-fill dam construction permits the fill material to be handled in larger mass and hence is suited to more intensive work mechanization. The feature highlights of the RCD method are: prepare a concrete mix in which water and cement contents are low enough to make the mixture non-flowing; spread this mix with bulldozers to form three layers, 50 to 75 cm per lift; and compact this spread with vibrating rollers. By repeating this process, the dam structure can be built continuously and safely, each time using a larger bulk of the mix for each spreading and compacting: for this process, conventional machines may be employed.

The advantage accruing from this RCD method, as applied to concrete gravity dam construction, has won worldwide recognition. One of the world's largest concrete gravity dams being built by this method is now under construction as the Ministry-of-Construction (Japan) project at Miyagase, Japan. (See Fig. 3. Execution flowchart of RCD method.)

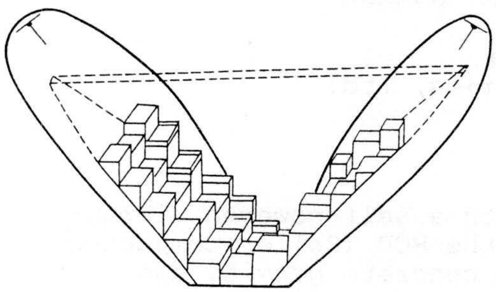


Fig. 1. Column method of execution
Concrete dam construction by building a plurality of columnar concrete blocks.

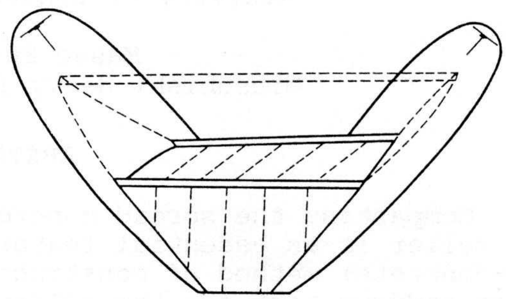


Fig. 2. Layer method of execution
Building dam proper in layers of concrete, forming each layer by spreading concrete over the entire area and compacting it by the roller.

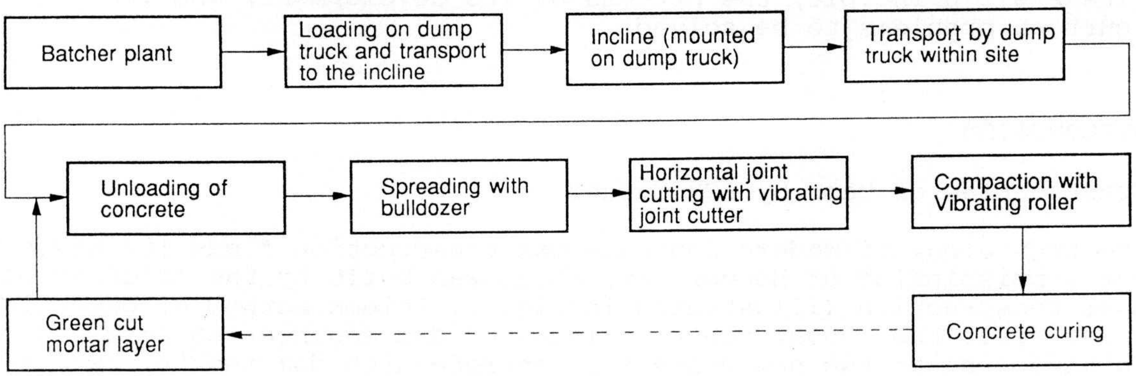


Fig. 3. Execution flow for RCD method

(2) Use of Vibrating Rollers for RCD Method and Necessity of Developing an Automatic Operation System

Concrete gravity dam construction by the RCD method is premised on the use of vibrating rollers, but this presents a problem in that the working area where the spread of non-flowing mix is compacted is generally so extensive that the roller operator would be forced to repeat operating the roller back and forth on successive parallel lanes. This would be obviously monotonous to him. Moreover, each back-and-forth compacting cycles has to be rigidly controlled if the required concrete quality in terms of compactness is to be attained. Here lies the need of an automatic operation system.

Such a system aiming primarily at releasing the roller operator from the drudge of monotonous repetition has to be computerized so that the specified accuracy of rolling-compacting operation can be secured. The system represented has been developed to meet these needs.

(3) Compacting Pattern

For the present system, each roller is to make a compacting cycle on the lane with its roll in non-vibrating mode and to follow this with five cycles in vibrating one. Thus, a total of six cycles per lane are required, as shown in the basic compacting pattern of Fig. 4.

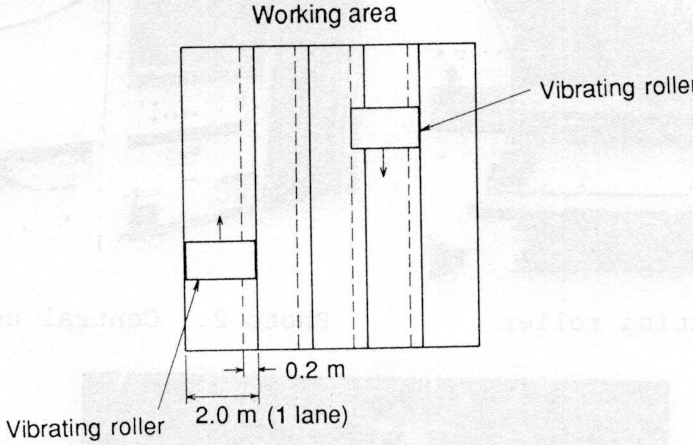


Fig. 4. Compacting pattern

After compacting one lane as above, the roller is to shift sidewise to the next lane and repeat the process thereon, making an overlap of at least 20 cm as indicated in Fig. 4.

2. DESCRIPTION OF AUTOMATIC OPERATION SYSTEM

(1) Equipment Included in the System

The automatic operating system, to be presently described on the basis of one-roller operation, uses a vibrating roller, a central control system, a roller-position detecting device (a mobile station on the roller and a ground station, fixed and stationary), a radio communication device, radio control devices, a vehicle controller, and roller control mechanism (pneumatic actuators). The system is conceptually illustrated in Fig. 5. Photos 1, 2 and 3 show the roller, central control system and ground station, respectively.

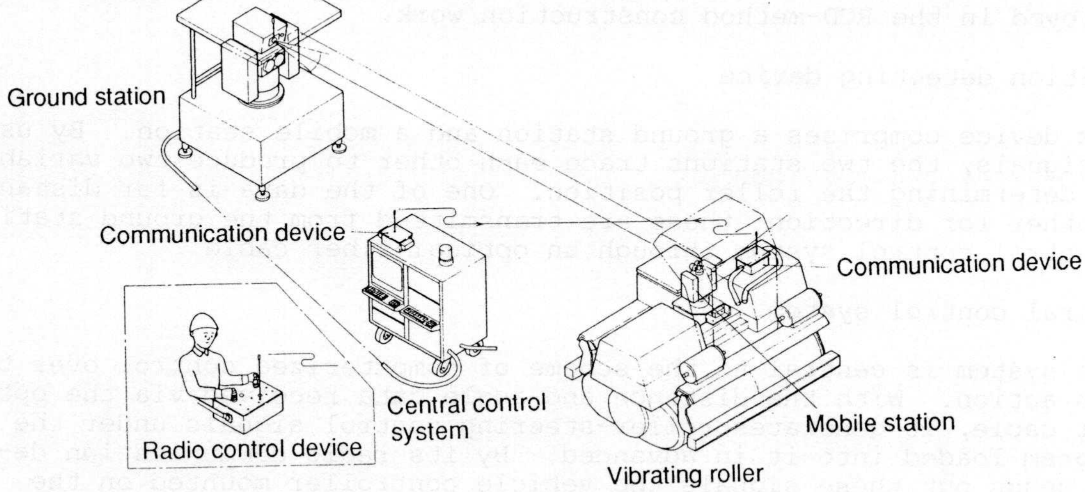


Fig. 5. Concept of automatic operation system

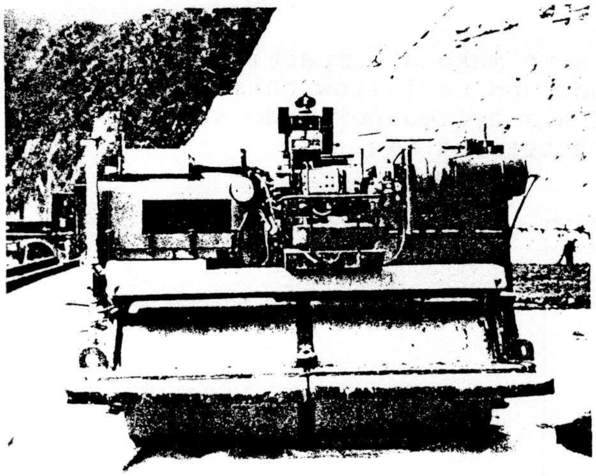


Photo 1. Vibrating roller

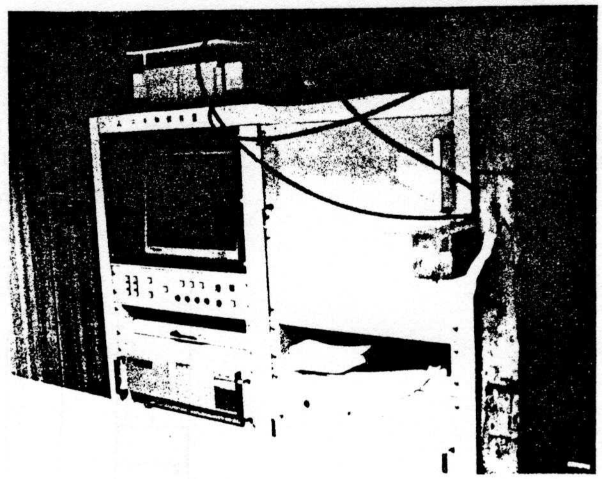


Photo 2. Central control system

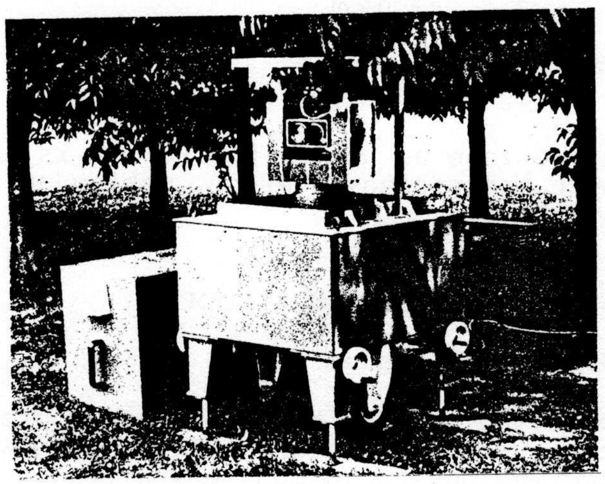


Photo 3. Ground station

(a) Vibrating roller

The German BOMAG-make BW200 has been selected for this system. BW200 rollers, built small and well-reputed for high efficiency, have generally been employed in the RCD-method construction work.

(b) Position detecting device

This device comprises a ground station and a mobile station. By using optical signals, the two stations trace each other to produce two variable data for determining the roller position. One of the data is for distance and the other for direction: these are transmitted from the ground station to the central control system through an optical-fiber cable.

(c) Central control system

This system is central to the scheme of computerized control over the roller in action. With the distance and angle data received via the optical-fiber cable, it generates roller-steering control signals under the work program loaded into it in advanced. By its radio communication device, it sends out these signals the vehicle controller mounted on the roller. It keeps constant watch over the roller in motion by displaying the roller's working conditions on the CRT screen and recording the roller operation in the floppy disk, both for use in managing the compacting work over the entire working area.

(d) Communication device

This device includes separate transmitters and receivers. The transmitter/receiver pair of mobile station and the similar pair on ground station serve as the means of two-way communication between two stations. The radio control device is a means of manually controlling the roller. It is an auxiliary device used by a nearby supervisor if and when he has to move the roller off harm's way, or to or from work.

(e) Vehicle controller and roller control mechanism

The roller-mounted vehicle controller processes the steering control signals from the central control system and operates the control mechanism consisting of pneumatic actuators, which are working components of the roller.

(2) System Configuration and Sequence of Compacting Work

First, the ground station is to be set up at a location commanding a full view of the working area and, at each corner of this area, a pole prism is to be set as a point of reference. The four points are numbered clockwise, O1, O2, O3 and O4.

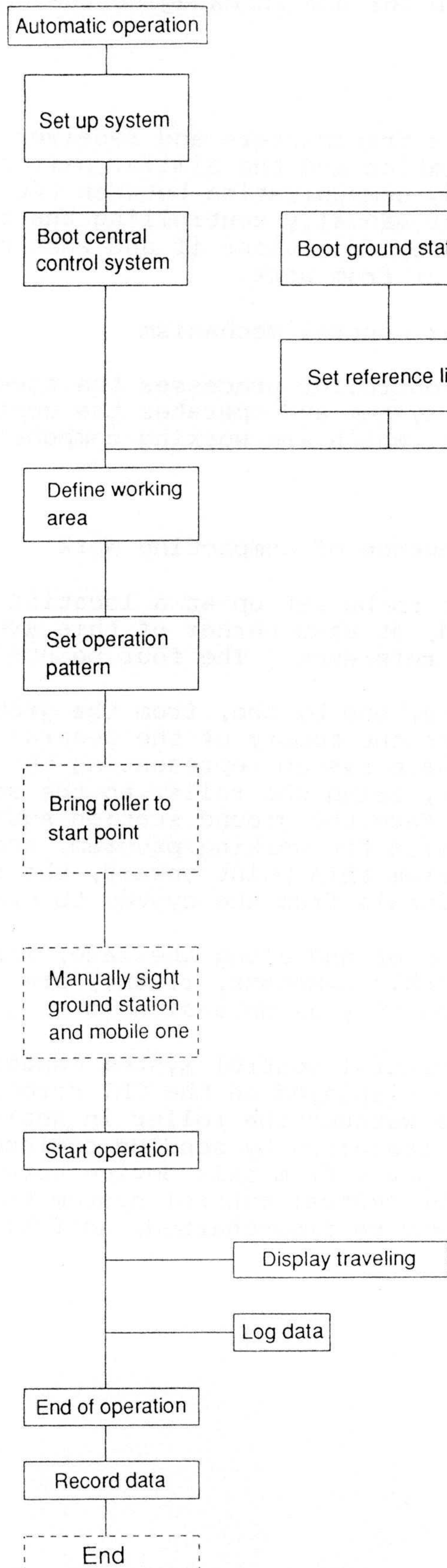
Next, sight the corner points, one by one, from the ground station and feed the corner-position data into the memory of the central control system, thereby establishing coordinate system representing the working area.

After completing these steps, bring the roller to the start position, and adjust its mobile station to face the ground station squarely. Now, load the central control system with the working program, and feed the start command into the system. From this point onward, the roller will run automatically according to the signals from the system to execute the program.

While the roller is in motion on and along the lane, its position and working conditions as well as trouble symptoms, if any, are detected and transmitted constantly and continuously as data signals to the central control system.

The system operator at the central control system manages the ongoing operation through the information displayed on the CRT screen. The supervisor at the radio control device watches the roller in action and, as necessary, intervenes the automatic operation by sending commands from the device to the roller. Command signals from this device have precedence over the steering signals from the central control system to the roller.

The basic working sequence may be flow-charted, as follows:


Automatic operation
Set up system
Boot central control system
Boot ground station
Boot mobile station
Set reference line
Define working area
Set operation pattern
Bring roller to start point
Manually sight ground station and mobile one
Start operation
Display traveling
Log data
End of operation
Record data
End

3. PRINCIPLE OF DETECTING THE VIBRATING ROLLER POSITION

The so-called ρ-θ (theta) method familiar to those versed in hyperbolic navigation, is the basis of the scheme employed in the present system to keep on detecting the position of the vibrating roller in traveling. The device used in implementing this method consists mainly of two devices, on being the ground station and the other the mobile station on the roller. For simplicity, the roller will be assumed in the description to follow.

The ground station measures distance ρ (between the station and the roller) and angle θ included between a reference axis and the straight line from the station to the roller. Since the roller is in traveling, these two, distance and angle, are continuously detected and measured within a working area.

The working area is generally rectangular and is defined by four points set up at the four corners, one at each corner: the vibrating roller is to work within this area. Here's how the working area is set:

By manually operating the ground station, the four points are sighted one by one to produce four data, O1, O2, O3 and O4, each representing a corner. These data are input into the central control system and recorded in its memory.

Fig. 6. illustrates an example of the rectangle so established, with the ground station indicated by a double circle symbol.

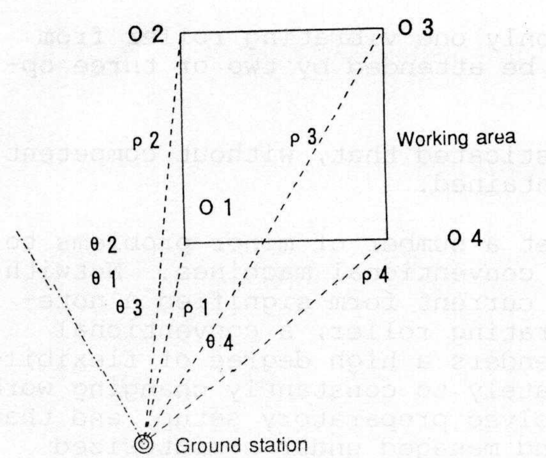


Fig. 6. Defining the working area

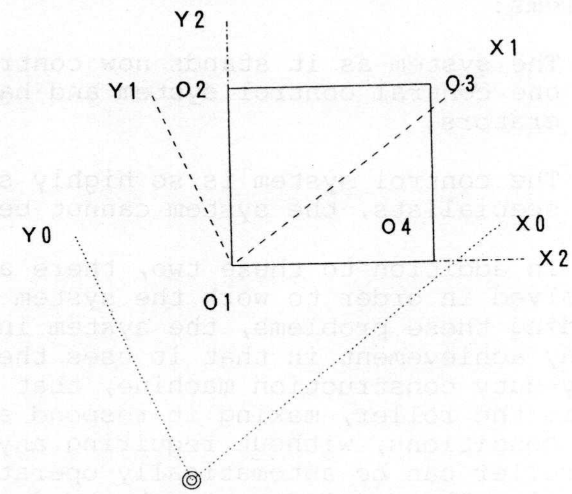


Fig. 7. Coordinate system of working area

In operation, the ground station shoots out a modulated light beam to the mobile station. The latter reflects this beam by its own prism back to the ground station. The reflected beam differs from the original beam in terms of phase. This difference in phase is measured to determine distance ρ.

The mechanism for measuring angle θ comprises two emitter-acceptor sets, one set in the ground station and the other in the mobile station. Each set has horizontal and vertical axes, which are each equipped with a servo mechanism and an encoder. Light from the emitter of one set is received by the acceptor of the other. In other words, the two stations keep on casting light onto each other and posture adjustment is effected in such a way that the acceptor will receive the incident light at its center. Signals from the encoders are processed to produce angle θ data.

Fig. 6. illustrates two data for each corner point: ρ1 and θ1 for O1, ρ2 and θ2 for O2 and so on, to describe the working area as a rectangular coordinate system, with O1-O2 as Y axis and O1-O4 as X axis. By the well-known software techniques, this coordinate system can be transposed sidewise and rotated on and around the origin (O1).

Suppose the roller is to run in the direction to target X1 as shown in

Fig. 7. In this case, the coordinate system is to be rotated to bring the X axis to the target direction X1. Thus, target direction can be sequentially shifted toward direction X0. Once the direction is set in this manner, the roller is to run automatically and be kept travelling on the directed course by constantly detecting and eliminating its angular and sidewise deviations from the set direction.

4. DEVELOPMENT CHRONOLOGY

A joint venture was undertaken by the Kanto Engineering Laboratory, Ministry of Construction and MHI in 1987 to develop an automatic operation system. Manufacture of prototype system was completed in the following year and was put to field test at the Miyagase dam site.

System testing, debugging and refinement had been repeated at the Kanto Engineering Laboratory until, in December, 1991, the system was finally placed in trial use at the Miyagase dam under construction.

5. SUMMARY

In putting the developed system to practical work at the dam site, note was taken of two problems to be solved for this system. Here are the problems:

(1) The system as it stands now controls only one vibrating roller from one central control system and has to be attended by two or three operators.

(2) The control system is so highly sophisticated that, without competent specialists, the system cannot be maintained.

In addition to these two, there are yet a number of minor problems to be solved in order to work the system with conventional machines. Notwithstanding these problems, the system in its current form signified a noteworthy achievement in that it uses the vibrating roller, a conventional heavy-duty construction machine, that it renders a high degree of flexibility to the roller, making it respond accurately to constantly changing work site conditions, without requiring any involved preparatory setup, and that the roller can be automatically operated and managed under computerized control. The development work and its results are expected to contribute much to the future of automation and robotization of construction machinery.

6. ACKNOWLEDGMENT

Thanks are due to members of the Automatic Vibrating Roller Operation System Development Committee and Working Group and to those of the Advanced Construction Technology Center Foundation and the Kashima-Ohbayashi-Toda consortium for the joint-venture construction work at Miyagase, without whose assistance and cooperation this system would not have grown to what is is today. We take pleasure in acknowledging the efforts made by the technical personnel of the Ministry of Construction concerned in developing this automatic operation system.

7. REFERENCES

- Revised Technical Guidelines on the RCD Construction Method (provisional)
- MHI Technical Journal, 1988-9 Vol. 25, No. 5