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MEASURING ROBOT OF THE DEGREE OF SOIL-COMPACTION

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ABSTRACT

This robot executes real-time measuring of the soil-compaction degree while running under its own power on compacted ground for site preparation, roads, dams, etc.

The basic conditions for the development of the robot are as follows.

- o Use shall be possible in a work environment of where bulldozers and other heavy machinery operate.
- o Running measuring shall be possible with remote control or automatically.
- o Accurate position detection shall be possible for the robot.
- o Consecutive, nondestructive, contact-free measuring of the soil-compaction degree shall be possible.
- o Real-time monitoring of the measuring results and the robot position shall be possible.

The development of this robot was executed as a link in the joint research (1985 to 1987) executed mainly by the Public Works Research Institute of the Ministry of Construction for "Development of a high-level construction technology system with use of electronics".

1. Introduction

In recent years, strong demands have been made for higher levels of construction technology to increase the safety of the construction work and to improve the effectiveness, the quality, and the accuracy. Here, the filling work, as a fundamental part of civil engineering, was taken up, and a higher level of work technology was aimed for. This robot is a robot system for real-time measuring of the soil-compaction degree with the purpose of higher efficiency and better safety for the soil-compaction work. The concrete development themes for the development of this robot were the development of a robot position measuring system and a real-time measuring system for the soil-compaction degree. For this, joint research by the Public Works Research Institute of the Ministry of Construction and the Mitsui Construction Co., Ltd., was executed since 1985, and this robot was developed as a measuring robot of the degree of soil-compaction combining these two systems.

This paper gives an outline of the measuring robot of the degree of soil-compaction and treats the position measuring system and the measuring system for the soil-compaction degree.

2. Outline of the Soil-compaction Measuring Robot

The measuring robot of the degree of soil-compaction (photo 1) is an unmanned self-propelled robot which uses the on-board measuring equipment for continuous measuring of the soil-compaction degree. In addition to the self-propelled measuring robot of the degree of soil-compaction, the authors also have developed a trailer-type robot (photo 2), pulled by a roller etc., while executing measuring.

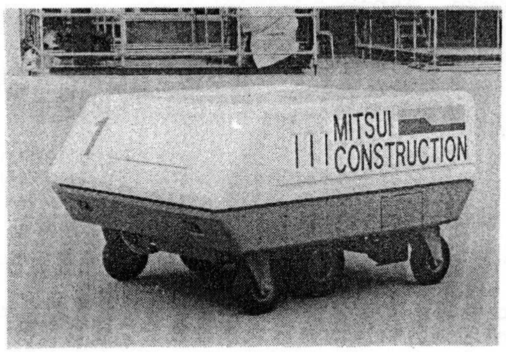

Photo 1
Self-propelled measuring robot of the degree of soil-compaction

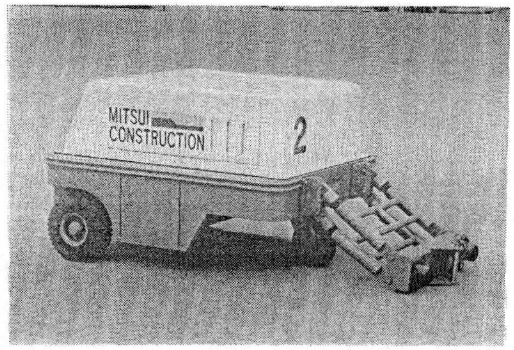

Photo 2
Trailer type measuring robot of the degree of soil-compaction

(1) Basic functions

The basic functions are the traveling function, the robot position detection function, the soil-compaction degree measuring function, the communication and display function, the teaching function, etc. The main basic functions are shown in Fig. 1

1) Traveling function

This is the drive part and wheel part function making stable two-dimensional movement on compacted ground possible. The traveling patterns are forward/back, left/right steering, and spin turn function, and travelling is executed as 6-wheel travelling with 2 driven wheels and 4 casters. The movement is controlled by a program, and posture control by means of mounted sensors is executed for advance, direction change, etc.

2) Position measuring function

The position measuring function is composed of two systems: the autonomous navigation system recognizing the position of the robot itself (magnetic azimuth sensor, vibration gyro, distance meter) and the system for relative position recognition (boundary information mat, sensor system), and the robot position can be detected over a wide field. This system permits position detection within an area limited by boundaries, and movement path recording, track designation, etc. are possible.

3) Measuring of the degree of Soil-compaction function

A newly developed back scattering-type nuclear density and moisture gauge is mounted on the robot, and the soil-compaction degree (dry density, moisture density, etc.) can be measured continuously, contact-free, and nondestructive during stop or traveling.

4) Communication and display function

The measuring results, the measuring position, and the present position of the robot can be monitored in real time, and the soil-compaction degree is transmitted to the manager for swift feedback to the soil-compaction work.

5) Teaching function

4 types of teaching methods can be used to specify the measuring points, the measuring time, the measuring frequency, and other measuring commands, as well as track and traveling range etc. to the robot.

. Manual movement measuring (wired manual operation)
. Remote control by the host computer (wireless operation)
. Wireless batch processing by the host computer.
. Batch processing by a mounted hand-held computer.

6) Safety function

Infrared sensors and touch sensors are installed, functions for voice traveling approach warnings, abnormal approach stop, contact stop, etc. are provided, and the safety of the operator is maintained.

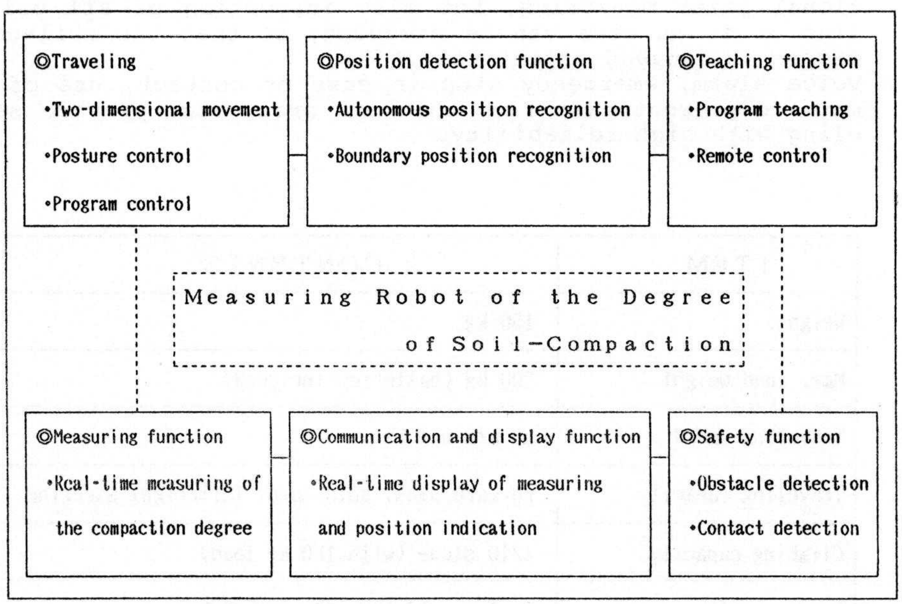

Fig. 1 Basic function diagram

(2) System composition and specifications

The robot specifications are shown in table 1.

The measuring robot of the degree of soil-compaction is composed of the following main systems.

1) Overall control system (main CPU)

This system is composed of a board computer, and it controls the subsystems for movement control, communication, and measuring. This system is the basis of the robot system. The CPU is a Z80, the main memory is 64 KB, and it has a 4 MHz timer. Two RS232C interface circuits are provided.

2) Movement control system (sub-CPU)

This is composed of a board computer, and it is the subsystem for robot movement control. The system has 8 PI/O ports and 2 A/D ports as sensor signal input boards and a relay board with 32 channels for robot drive control.

3) RI instrument operation/display unit

Together with measuring control for the discrete-type RI density/moisture meter, measuring result operations and display and transmission of the measuring results via the PI/O ports to the main CPU are executed.

4) Host computer and wireless modem

Measuring specifications, traveling path specification, measuring results, present position information of the robot, etc. are transmitted from the main control system to the host computer via the wireless modem (RS232C), and they are displayed.

(3) Special features

The robot has the following special features.

- o Unmanned measuring can be executed automatically without workers entering into the field.
- o The on-board microcomputer executes real-time data analysis, data gathering, and transmission, and swift feedback to the work execution side is possible.
- o As the traveling route can be set freely, not only the conventional point measuring, but also inspection of all points on a line or in an area can be executed, so that the soil-compaction degree is managed effectively.
- o Voice alarm, emergency stop in case of contact, use of boundary mats to prevent exit from the work area, etc. provide safe traveling with high reliability.

ITEM	CONTENTS
Weight	150 kg
Max. load weight	200 kg (batteries included)
Traveling speed	20 m/min + 5%
Traveling capacity	Forward/back, spin turn, left/right steering
Climbing capacity	1/10 slope (with 150 kg load)
Power supply	Battery DC 12V ×2, 50Ah/2 hours
Braking distance	Emergency stop : 20 to 30 mm
	Traveling command OFF : 260 mm
Emergency stop function	Emergency stop with contact detection
Alarm function	Voice approach alarm
External dimensions	1400 × 800 × 750 mm

Table 1. Robot specifications

3. Position Measuring System

The position measuring system of the measuring robot of the degree of soil-compaction uses a combination of the following two methods.

Within the measuring area, an autonomous navigation system is used, where the on-board sensors of the robot detect the direction and distance of the robot travel and grasp the present position of the robot, and at the boundaries of the area, a method with reading of position information from information mats installed at the boundaries is used to grasp the present position of the robot.

(1) Autonomous navigation system

The traveling direction and the traveled distance are obtained by distance sensors and direction sensors mounted on the robot itself, and they are used in combination by this system for position calculation. The specifications of the sensors used in this autonomous navigation system are shown in table 2.

This method uses encoders as distance sensors, and it is designed for operation coupled to left and right drive wheel. The two direction sensors are a vibration gyro and a magnetic azimuth sensor. This combination of two sensors is used as vibration gyros are strong in regard to magnetic noise (close to magnetic bodies etc.) while they are susceptible to mechanical noise (vibrations etc.), while the opposite applies for magnetic azimuth sensors (photo 3), and this system uses the strong points of both to compensate for the weak points, so that the reliability of the direction control is increased.

(2) Information mat system (patent pending)

This is a position measuring system composed of information mats (photo 4) installed at the boundaries of the measuring area and sensor for boundary reading, installed on the robot.

The information mats are composed of metal boxes forming patterns according to the information, and rubber material for their protection. The information mats contain information that they are the boundary, and information in regard to the position on the boundary. The robot uses magnetic proximity sensors to read this information, so that it can grasp that it has reached the boundary and where it is on the boundary. A proximity sensor is a sensor which can detect metals without contact, and it has excellent resistance against environmental influences (heat, humidity, direct sunlight, etc.). The output signal processing also is easy, and the price is low.

Information mats have the following special features.

- The min. reading unit length (resolution) can be set as desired by means of the mat width.
- Excellent weather resistance, use in water or in the ground also is possible.
- No maintenance required, excellent durability.
- No current leakage or noise etc., and no influence onto other equipment.
- The work of all kinds of work machines (bulldozers, rollers, etc.) at the compaction work site shall not be impaired.
- There shall be no influence from the vibrations, dust, etc. accompanying the passage of the work machines.

By use of this position measuring method with use of information mats for supply of correct position information in addition to the autonomous navigation system, errors accumulated inside the measuring range are cancelled at the boundaries, and the position measuring error always can be kept within a constant range. In addition, use of the information mats prevents escape of the robot from the measuring area and not required entry of workers into the measuring area.

ITEM	Magnetic azimuth sensor	Vibration gyro	Distance meter
Detection	Azimuth	Horizontal turning angle	Speed
Unit	Degre es	Degrees	rpm
Resolution	0.1°	0.1°	0.9cm
Accuracy	±1°	±1°	±90cm
Others	Detection range: 0 to 359°	Detection range: -180 to +180	

Table 2 Sensor specifications for the automous navigation system

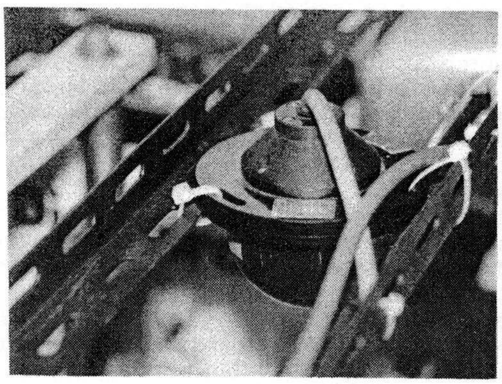

Photo.3 Magnetic azimuth sensor

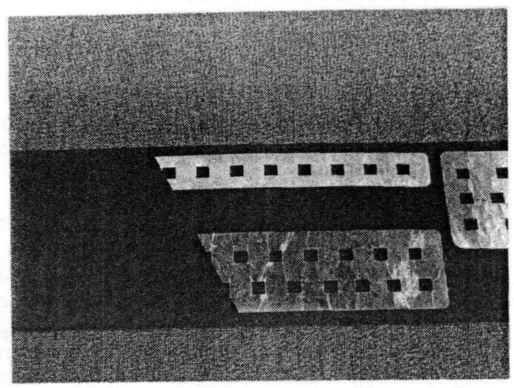

Photo.4 Information mat

4. Soil-compaction Degree Measuring System

(1) Outline

For automation an better efficiency of the soil-compaction work, a system is required to measure the soil-compaction degree quickly and continuously during the work and to provide feed-back to the soil-compaction work. For this reason, the conditions shown below were set, and development of a soil-compaction degree measuring system fulfilling these conditions was executed.

- o Quick and quantitative measuring shall be possible, and the measuring results shall have sufficient accuracy for the work management.
- o Measuring with continuous movement over the specified area shall be possible.
- o Nondestructive measuring shall be executed.

RI is used as a method for quick and quantitative measuring of the soil-compaction degree, but measuring with continuous movement is not possible with the presently generally used surface transmission type RI density and moisture meters where radiation source rods are driven into the ground, and strictly speaking, this is not a nondestructive measuring method. On the other hand, the surface back scattering-type nuclear density and moisture gauge fulfills the conditions for continuous movement measuring and nondestructive inspection, but the research until now (Ministry of Construction, Public Works Research Institute documentation No. 434 and No. 580) has shown many problems in regard to the measuring accuracy, so that wide-spread use was not reached.

The back scattering-type RI density and moisture gauge developed this time (photo 5) makes sufficient use of the characteristics of a back scattering-type, and the measuring accuracy has been improved by application of the most modern technology for the instrument configuration and the data analysis method. These measuring instruments are composed of a density meter and a moisture meter.

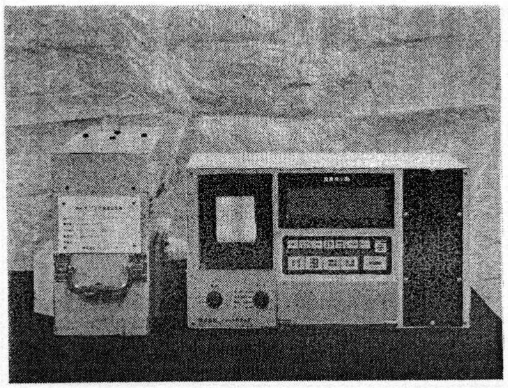

Photo 5 Back scattering-type nuclear density and moisture (newly developed)

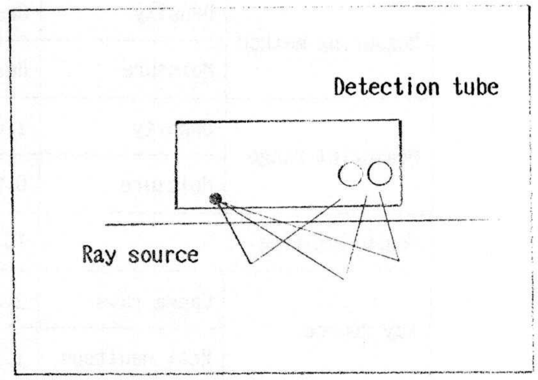

Fig.3. Outline of the back scattering gauge

(2) Special features and specifications

1) Measuring range (in depth direction)

With the conventional research the measuring range used to be concentrated at the surface or in the very shallow part, and it has been pointed out that it is required to obtain a measuring range to a suitable depth for work management. This research investigates the instrument composition, the analysis methods separate by energies, etc. for this instrument, and measuring was made possible to a depth of 15 to 20 cm in the case of actually compacted earth.

2) Correction formula

As continuous moving measuring is the purpose of this instrument, a correction formula must be obtained which takes the variations of the air gap between the instrument and the ground surface into consideration. For this, the following model formula including the mutual action between air gap and humidity density and between air gap and moisture density was set, and regressive analysis was executed.

Model formula: $R = a + bG + c\rho + dG\rho$

Target variable: R (coefficient ratio)

Explanation variables:

ρ (humidity density, moisture density gf/cm^3)

G (gap, cm)

As the result, the following correction formulae were obtained.

Humidity density correction formula:

(Correlation coefficient: 0.976)

$Rg = (1.834 + 0.065\ G) - (0.520 - 0.070\ G) \times \rho t$

Moisture density correction formula:

(Correlation coefficient: 0.996)

$Rn = (0.118 + 0.015\ G) - (1.730 - 0.261\ G) \times \rho m$

By inclusion of the influence of the air gap into the correction formula for this instrument, it is principally possible to remove the error caused by the air gap, and continuous movement measuring has become possible.

3) Specifications

ITEM		CONTENTS
Measuring method	Density	Gamma ray dispersion type
	Moisture	Heat neutron dispersion type
Measurint range	Density	1.00 to 2.50 t/m
	Moisture	0.05 to 0.09 t/m
Measuring time		15 sec or more (optional in units of seconds)
Ray source	Gamma rays	2.3 MBq (70 Ci) Co-60
	Heat neutrons	1.1 MBq (30 Ci) Cf-252
External output		16 bit parallel I/F
Measuring indecation method		External signal command
		Panel operation
Others		Function for measuring of the air gap to the measuring surface

Table 3. Specifications of the back scattering gauge

(3) Application range

For this measuring system, applications can be considered for the following fields in addition to measuring of the soil-compaction degree.

- o Measuring of the not visible part of excavations (behind molds etc.)
- o Measuring of the soil-compaction degree of low slump concrete (RCD etc.)
- o Measuring of thickness and density of asphalt paving
- o Grasping of the pouring condition at the time of concrete pouring
- o Ground property investigations (checking for cavities and spring water)

5. Conclusion

This is the first self-propelled measuring robot in Japan with the purpose of field measuring. The position measuring, travel control, and teaching and communication systems obtained by the development of this robot probably will be applied as the basic system for construction robots in various fields. Especially the position measuring system can be called a characteristic system for construction applications, not seen with FA transport robots, and it is believed that it will be used widely for the development of robots traveling in the field.

The future development themes for improvement of this system are listed below.

- Development of a travel function for bad surfaces like irregular, soft, or sloping ground etc.which require a caterpillar method.
- Improvement of the position measuring accuracy in the case of wider movement range.
- Development of a construction robot AI system with selection of the measuring specifications (frequency, time, etc.), judgement of the measuring results, etc.
- Higher speed for control and communication by higher CPU speed and larger memory

It is intended to substantiate these functions and to aim for realization of these functions and application to actual work.

(Reference literature)

- Ministry of Construction, Public Works Research Institute documentation No.434, NO.580 "Measuring of the site density and moisture amount of earth by RI use".
- 22nd Soil Engineering Research Publication Meeting, No.826 "Contact-free test method for the compaction degree of soil (part 6)", Shimazu, Minami, Umezono, et al.
- Collection of the technological talks of the 42nd annual meeting of the Japan Society of Civil Engineers, volume 6, part VI-39 "Research in regard to the measuring technology for the soil compaction degree", Shimazu, et al.