A Non-prism Laser Measurement System Using Image Control

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Abstract

A non-prism laser measurement system using image control is described. The device combines imaging, non-prism laser measurement, and computer control techniques to achieve an early understanding of topography and the amount of earthworks required as well as improved work safety. Consisting of CCD cameras, non-prism laser measurement equipment, rotational positioning equipment, and a computer, it is operated interactively using a keyboard or mouse. The laser is of the lowest power class, at less than 0.16 mW output, but allows measurement at distances up to 500 m with a precision of 1 cm. The system is currently in use during site preparation work for the Anan Converter Substation of Shikoku Electric Power Company, where it is assisting in the early understanding of changes in earth volume and topographical control.

1. Introduction

One of the most important pieces of information in cutting and filling work is the actual change in earth volume C (cutting/filling after compaction). Earth volumes are estimated in advance based on geological data obtained from test boreholes at the site. However, actual earth volumes are often quite different from these estimates, leading to an eventual need to change the elevation of the planned ground level or to redesign the structures during construction. For this reason, accurate understanding of changes in earth volume through periodic precision measurements of the amount of cutting and filling is essential to construction management, since it provides warning of the need for design changes as early as possible.

Conventionally, measurements have to be taken during daylight hours, when many construction machines are in operation, so they are dangerous and time-

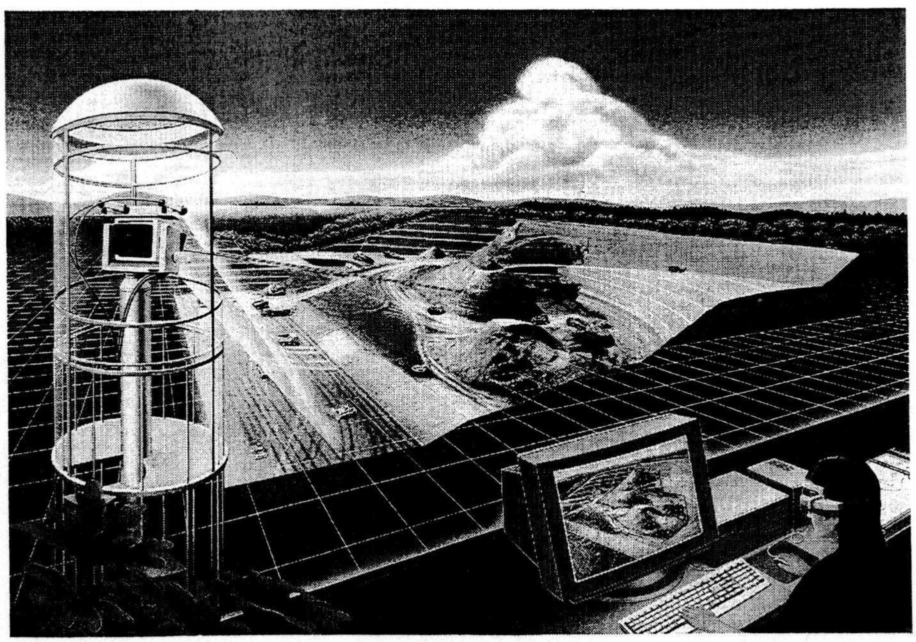


Fig. 1 Conceptual illustration of system

consuming. Improved methods of measurement have been long sought-after, in the hope that safety management and progress management can be improved.

The new system described here (Figure 1) provides an efficient means of three-dimensional measurement by combining the following techniques:

(1) Non-prism measurements for high-precision

(2) Image control to calculate measurement points using site images and PC-generated images through synthesis and computation

(3) Computer processing and control of image input, computation, and equipment control

2. System outline

2.1 System configuration

As shown in Fig. 2, the system comprises non-prism laser measurement equipment, a pair of CCD cameras, and a rotary drive unit for setting their orientation as well as a computer and data analyzer to control them and compute the three-dimensional position of measurement points. The functional composition of each equipment is illustrated in Fig. 3.

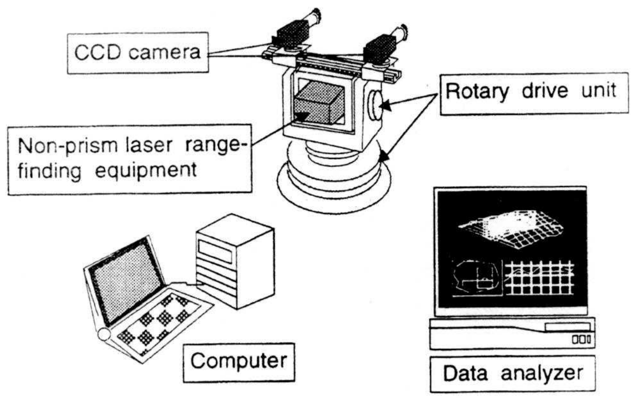


Fig. 2 System configuration

2.1.1 Non-prism laser measurement equipment.

Laser pulses are directed at the target, and the return time of the light is measured to calculate the distance from the target (time x light speed/2). Distance measuring performance thus depends greatly on the precision and stability of the clock, the laser output, and the optical system. Our system features a laser output of less than 0.16 mW. It takes 0.5 to 1 second to measure distance (depending on the measurement mode), and measurement

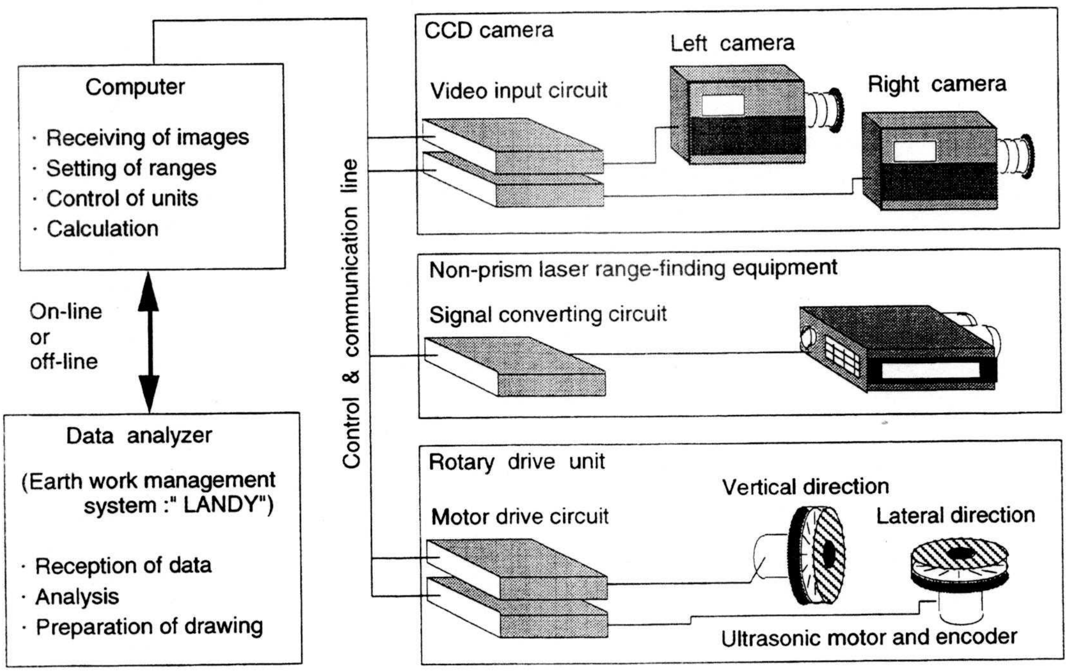


Fig. 3 Functional configuration of system

precision is 1 cm. The system incorporates special additions to the computation method to minimize the effects of disturbances such as dust, mist, or fluctuations in air characteristics.

2.1.2 CCD cameras.

CCD cameras are used to set up the measurement range and to obtain visual confirmation of measurement points. The two cameras allow for a three-dimensional confirmation of topographical features. This allows the operator to remotely check topographical changes and set measurement ranges from in front of the PC monitor. The optical axes of the two cameras are parallel with the axis of the laser measurement equipment, also the distance between the sight points or cross angles can be varied.

2.1.3 Rotary drive unit.

The rotary drive unit orients the sensing equipment (laser measurement equipment and CCD cameras) around the vertical and horizontal axes, positioning it as required. It also calculates how much rotation is needed, controls rotary motion, calculates rotated angles, and controls communications with the computer. A rotary encoder is used to read the angle. Drive is by an ultrasonic motor, which features compact size, low weight, high rotational torque, and precision control.

2.1.4 Computer unit.

The computer unit receives images, stores them, sets measurement ranges, computes measurement points, and computes and stores measurement results. It also controls the transmission and reception of signals and measurement data from the sensor equipment and rotary drive unit, while also taking overall control of the system.

2.1.5 Data analyzer.

The data analyzer prepares various types of drawings, such as sections, based on the measurements and outputs them. It is operated as an earth work management system (LANDY System).

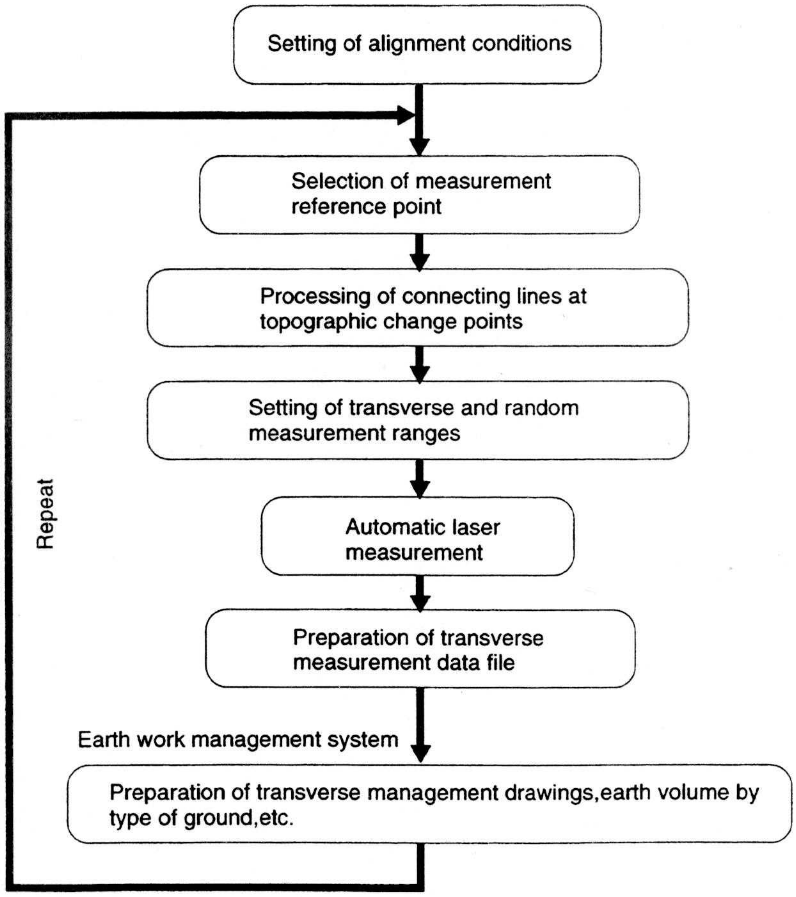


Fig.4 Flow diagram of measurement process

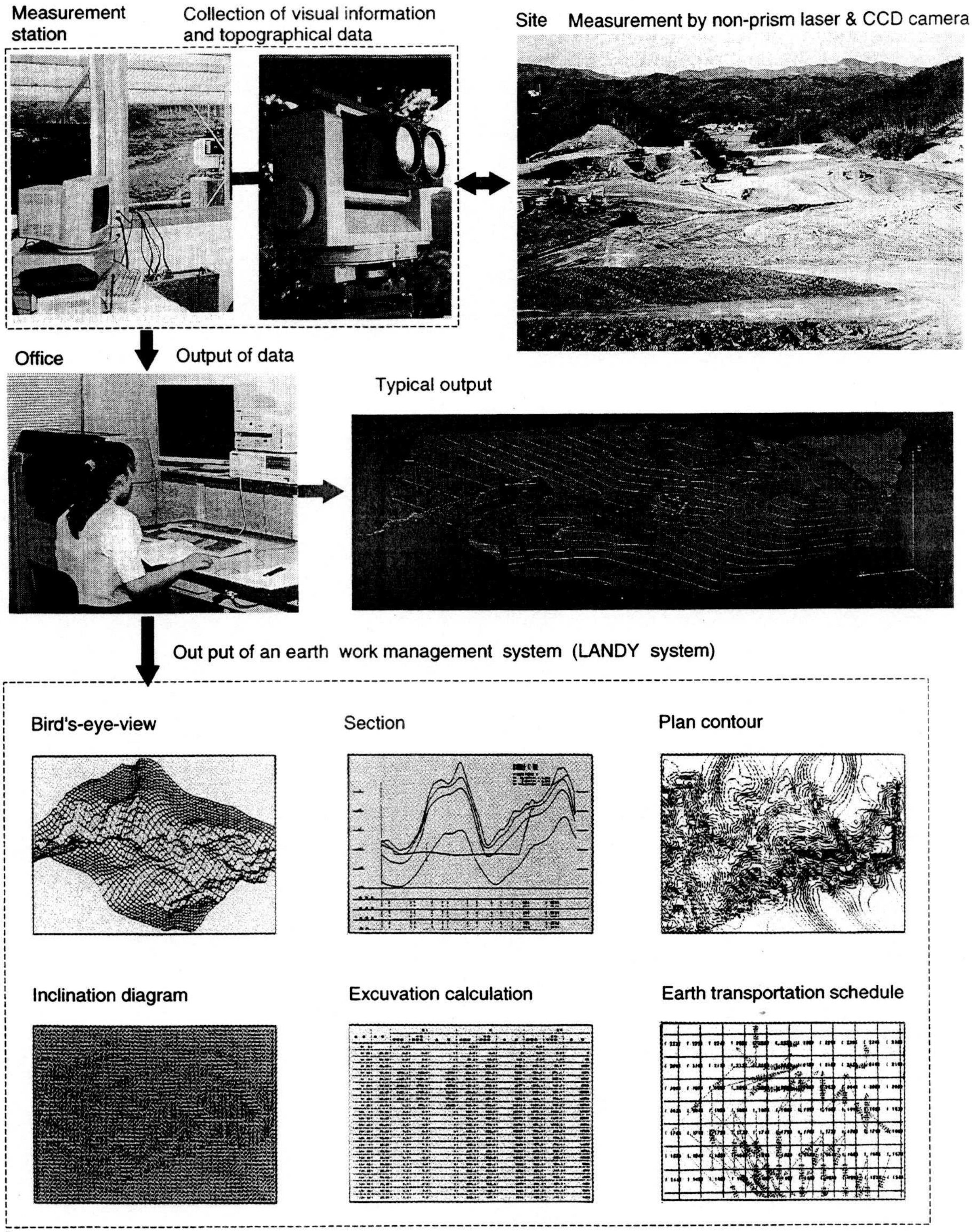


Fig. 5 Operational procedure (site preparation for Anan Converter Substation, Shikoku Electric Power, Co.)

2.2 Measurement procedure

The measurement and analysis procedure can be divided into three main stages: the setting of basic conditions, automatic measurement, and data analysis (Figs. 4 and 5).

2.2.1 Basic condition setting.

(1) Registration of transverse alignment

The transverse alignment, such as a straight line, a single curve, or a clothoid curve, should be registered according to the purpose of measurements.

(2) Installation of equipment

The sensor equipment and other items should be placed at known coordinates before setting the reference orientation and other conditions(Photo1).

(3) Registration of reference points and camera conditions

The coordinates and directional angle (horizontal orientation and vertical angle) of the reference point where the laser is located should be registered. The various camera constants should also be registered to allow proper representation of measuring points and measurement ranges on the monitor.

(4) Setting of measurement range

Using the mouse, the measurement range, which can be chosen freely, should be traced over the site image shown on the monitor.

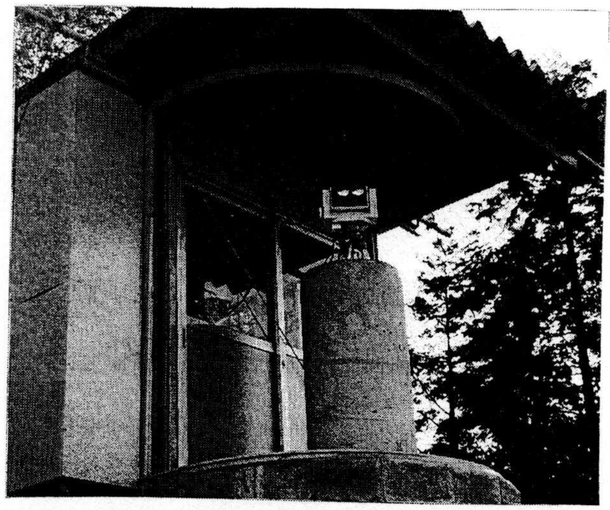


Photo 1 Installation of equipment

(5) Data input of topographical change points

At sites where there are frequent topographical changes, it is necessary to automatically increase the number of measurement points to obtain the more detailed topographical measurements required. Their positions should be confirmed on the monitor and the locations of topographical changes registered.

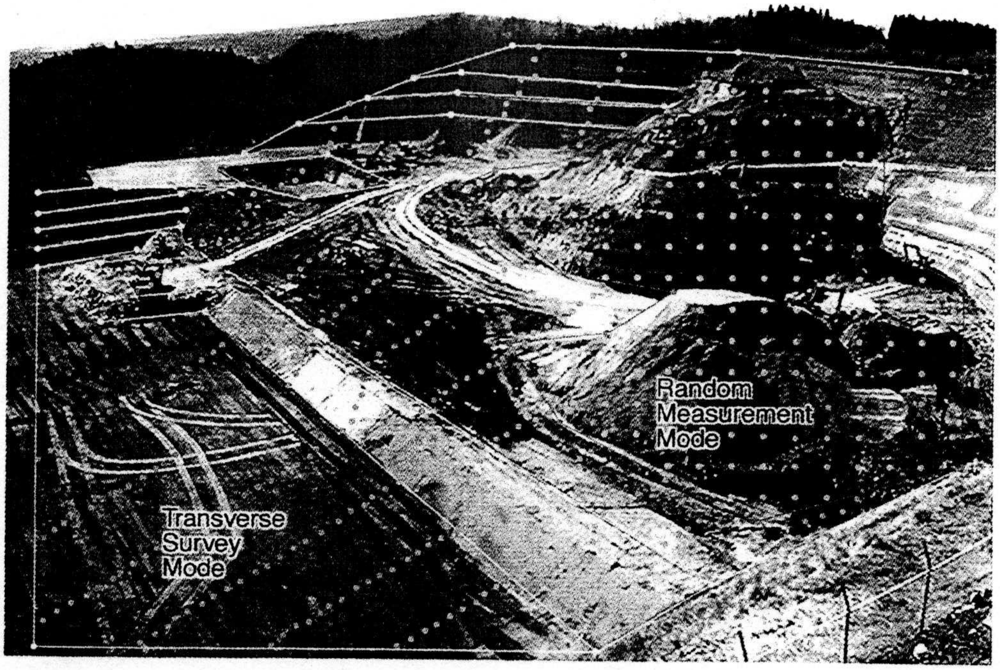


Photo 2 Sample screen showing a measurement point and the range of measurement

(6) Setting of measurement conditions

The intervals between measurement points and the timing of laser measurements at each point should be set.

2.2.2 Automatic measurement.

(1) The computer calculates the directional angle to each point to be measured.

(2) The rotary drive unit and laser equipment carries out the positioning and range measurement based on the calculation results.

(3) Computer operates on the measurement results and saves them as three-dimensional coordinates.

2.2.3 Data analysis.

The three-dimensional coordinate data saved by the computer are linked to an earth work management system (LANDY System). Then necessary measurement data are automatically read based on instructions such as lateral tolerance centering around the design transverse line and are automatically output in the most suitable form, such as transverse data or transverse drawings.

3. Features of the system

By linking imaging with non-prism range measurements, the system achieves considerable labor saving while also accelerating the process of in-situ measurements. It offers the following major features:

(1) Full automation of measurement

Workers are required only when initially placing the equipment and to set the initial conditions. Unless any changes are made to the location of the equipment or the settings, the system can then make repeated measurements or periodic measurements according to stored instructions on a fully automatic basis 24 hours a day.

(2) Remote control

Once the equipment is in place, a measurement area can be set and automatic measurement instructions issued from the computer monitor. Remote control is also possible using a wire communication (telephone line or LAN) or radio (satellite or SS).

(3) Simple operation

The system allows interactive operation using the keyboard or mouse, so a user with little or no special knowledge or experience can learn its operation quickly and easily.

(4) Unmanned measurement modes

The system operates in two modes: transverse survey mode, in which measurements are taken along a designated transverse line within the measurement area, and random measurement mode, in which measurements are taken at designated directional angles within the measurement area. A combination of these two types of measurement enhances the efficiency of automatic measurements (Photo 2).

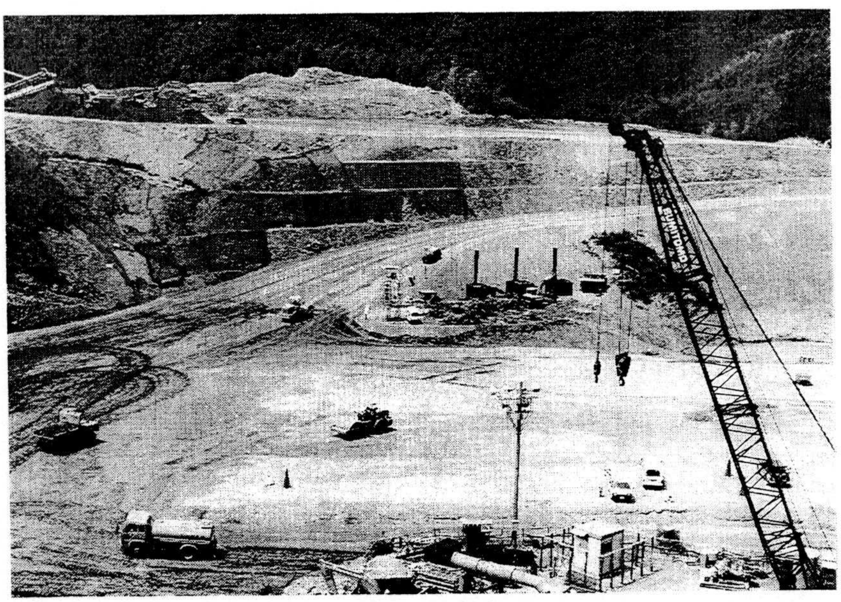


Photo 3 Site preparation for the Anan Converter Substation

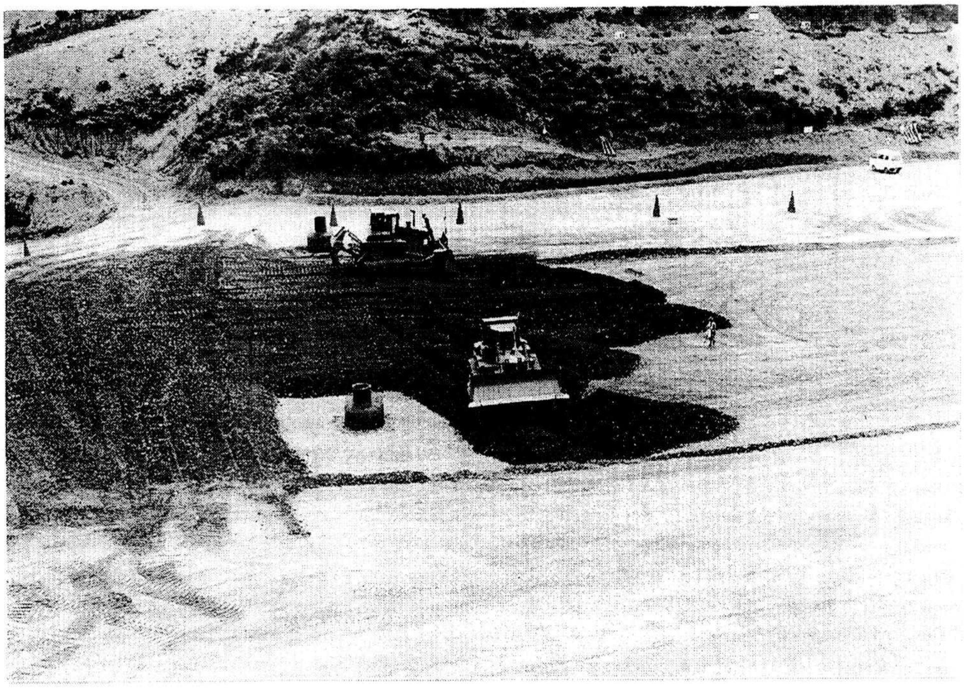


Photo 4 Site preparation for the Anan Converter Substation

(5) Uninterrupted processing from measurement to output

The process of automatic measurement, analysis, and output is implemented in a single, integrated procedure. This allows the system to be introduced where needed in the shortest possible time.

4. Application

4.1 Outline of project

The system is currently being used to prepare the site for the Anan Converter Substation of Shikoku Electric Power Company. This large project involves an effective area of 73,000 m^2, and involves a cut volume of about 800,000 m^3 of cut and about 920,000 m^3 of fill. The equipment that will ultimately be installed on the converter substation to be built on this land requires that certain uneven settlement limits are not exceeded. Earth may be filled up to a maximum of 35 m; considering this large scale, the fill that will ultimately serve as the foundation ground must be of sufficient quality.

The new ground is to be at 120 m, a difference of 105 m from EL = 15 m, and the cutting and filling work is mainly concentrated in a narrow strip of land. This difficult work needs to be done as safely as possible. Under these circumstances, the three-dimensional image measurement system was introduced to the site to achieve labor saving and improved implementation and management of the cutting and filling work (Photo 3 and 4).

4.2 Results of application

The system was used during the work described above, achieving the results outlined below.

(1) The precision of measurements by the non-prism laser equipment is confirmed to be 1 cm, or equal to that of conventional surveying methods (Table 1). Workers need no longer work overtime on days off, since the system is capable of unmanned operation even at night.

(2) The system allows measurements to be remotely controlled on the basis of data shown on the monitor, and this is confirmed to have a positive effect on safety monitoring and construction management.

(3) The system enables various data, such as boundaries between different rock types, to be linked into the earth work management system. This allows quick output of drawings and earth volume tables, as well as quick and detailed understanding of earth volume changes.

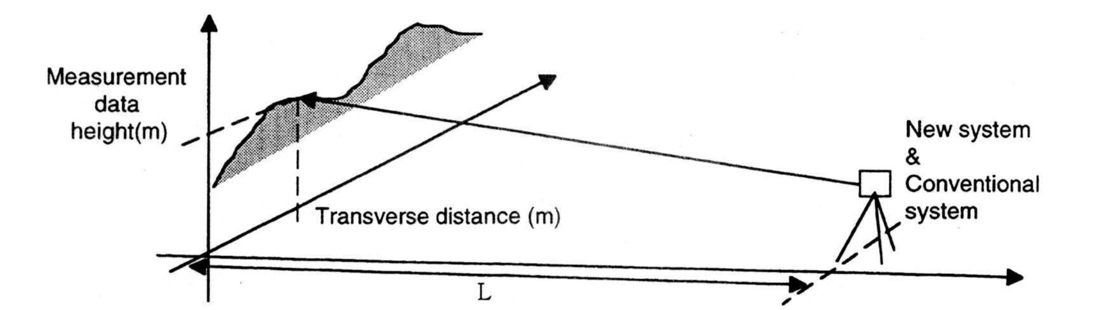
5. Conclusion

Rapid topographical measurements or geological measurements are crucial to construction management during site preparation work, since such work often entails moving huge amounts of earth on a daily basis.

The introduction of this three-dimensional image measurement system allowed unattended three-dimensional topographical measurements to be taken

Table 1 Results of transverse measurement precision evaluation

Transverse distance(m)	New system height(m)	Conventional system height(m)	Difference δ (mm)	Transverse distance(m)	New system height(m)	Conventional system height(m)	Difference δ (mm)
35.075	19.089	19.077	12	46.485	18.979	18.964	15
35.134	19.083	19.077	6	47.165	18.941	18.957	-15
36.218	19.059	19.066	-8	47.523	18.947	18.953	-6
38.716	19.034	19.041	-7	48.213	18.936	18.946	-10
39.666	19.041	19.032	9	48.278	18.934	18.946	-11
40.269	19.039	19.026	13	48.505	18.930	18.944	-14
42.701	19.010	19.001	8	49.333	18.923	18.935	-13
45.203	18.989	18.976	13	49.466	18.918	18.934	-16
45.294	18.983	18.976	7	49.556	18.918	18.933	-15
45.331	18.964	18.968	-4	49.903	18.924	18.930	-5
			$\pm\sqrt{(\Sigma \delta * \delta \div (N-1))} = \pm\sqrt{(2,443 \div (20-1))} = \pm 11mm$				



during the night, rather than in the daytime when heavy equipment is in operation. As a result, the labor requirements for measurement were considerably reduced.

The important processes of measurement are integrated in real time with the earth work management system, meeting the original objective of the system: to understand actual earth volume changes at the earliest possible stage of work.

The authors intend to direct future efforts toward the development of further advanced functions, such as the automation of topography recognition and tracking the movements of mobile equipment, such as heavy machinery, thus evolving the system into a more sophisticated measurement technique.

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