Automation and Robotics in Construction XII
E.Budny, A.McCrea, K.Szymanski (Editors)

The Tele-Earthwork System Best Adaptable to Remote-Operated Construction Equipment

Yoshiro Ohmori[1], Group Leader, Minoru Mano, Engineer, Devastated Unzen Reconstruction Project with Unmanned Construction System, Civil Engineering Division, Fujita Corporation

Fujita No. 3 Building, 5-23-15 Sendagara, Shibuya-ku, Tokyo 151, Japan

Abstract

The Tele-Earth Work System is intended to ensure the safe performance of a series of earthwork, from the excavation of soil to the loading, transportation and disposal of the excavated soil, through remote control steered from a centralized control room located away from the working areas, by using a variety of field monitors which display stereophotographs and computer graphics of pieces of unmanned heavy construction equipment in operation at construction site, which are transmitted from communication relay vehicles.

In the operation of construction equipment through remote control, advising the operators of the status of the equipment and their surrounding conditions accurately is essential. With these information judged overall, the working environment similar to that of manned equipment operation can be accomplished, through efficient operation of remote operated equipment as well.

Actual field operation included breaking rocks with a breaker, digging up soil by using a hydraulic shovel, gathering excavated material with a bulldozer, and loading it on dump trucks for disposal at an off-site yard. This paper describes how a series of the operations of these unmanned equipment were remote-controlled from a control room located more than 100 meters away from the project site.

1. INTRODUCTION

The development of electronics and mechatronics in recent years has been notable. Introducing such advanced technologies into automation as well as into the robotization of construction equipment has been required not only by the construction industry but also by society in order to ensure more rationalized construction, more labor-saving and to further improve the labor environment.

We at Fujita Corporation have taken prompt and continued steps to incorporate these advanced technologies into construction in order to promote automated and labor-saving construction. In addition, the company has, without delay, established a special organization to perform assignments for the development of technologies on its own.

The automation and robotization of heavy construction equipment is one of these tasks, and work on this task has continued up to the present time.

This paper discusses the ways in which we addressed the task of maneuvering remote-operated construction equipment under the tele-earthwork system employed for the removal of volcanic rocks erupted from Mt. Fugen, Kyushu district, Japan.

2. SYSTEM CONFIGURATION

2.1. System Overview

The Tele-Earthwork System has been designed so that a centralized control room be provided at a point distant from the area where earthwork is to be carried out. This was done in order to maneuver pieces of construction equipment through a communication relay car, for the safe execution of a series of work ranging from the excavation of earth, to the loading, transportation and disposal of the excavated material. Computer graphics and field monitors were used.

To ensure the remote operation of construction equipment, it is essential to accurately know the status of all the construction equipment at work on the field and their surrounding circumstances. Through the integrated judgment of such information which ensures their remote operations, they can be allowed to operate as if they were manned. With the aim of ensuring more efficient field operations, further study has been underway. Figure 1 is a conceptual illustration of the system.

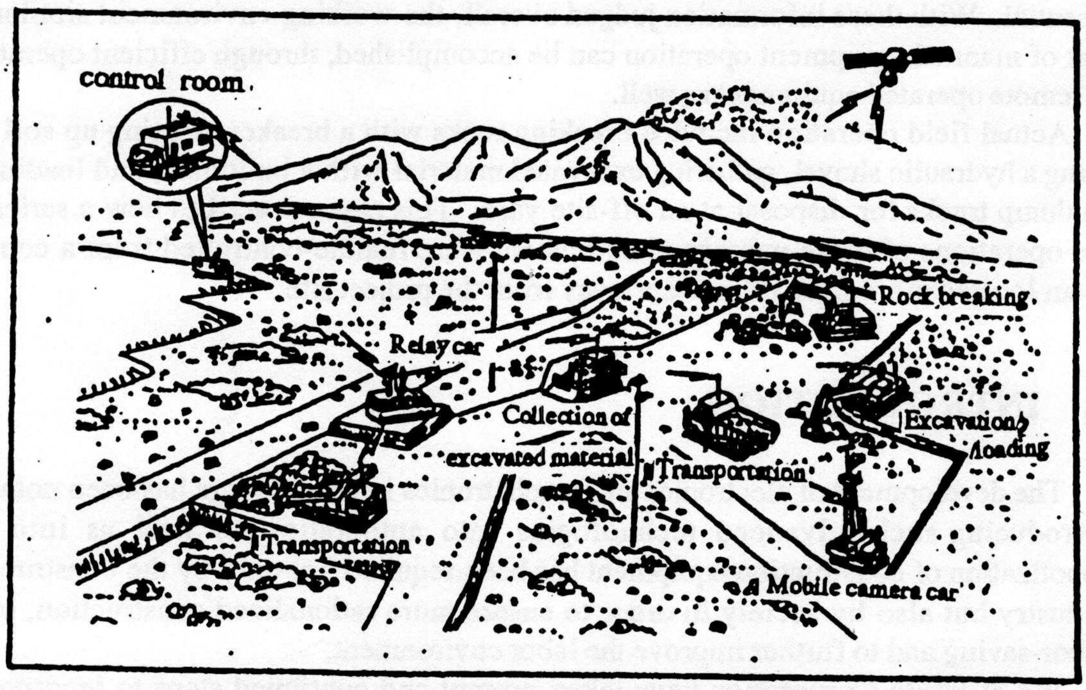

Figure 1. Conceptual illustration of the Tele-Earthwork System.

2.2. Construction Equipment

The removal of rocks needs a series of construction equipment, from excavators to loaders, transportation vehicles and breakers. Breakers smash rocks, hydraulic shovels dig up the ground, and bulldozers gather the dug-up material, which is then loaded onto dump trucks and transported to outside the unmanned construction site area. Such mechanical operations were remote-controlled from a control room located 100 to 1800 meters away from the site.

Mechanical imbalances had been observed at early stages, which were absorbed by using larger equipment to meet the increasing scale of work. The operators gradually improved their operating techniques through the repetition of practical operations, finally achieving the skill of performing earthwork with the efficiency almost equal to a manned operation. Table 1 lists the types of the construction equipment operated through the Tele-Earthwork System.

2.3. System's Features

(1) Unmanned construction was able to be executed by remote operation at the control room 1,800 meters away from the construction site.

(2) Field work was able to be managed through global multimedia including satellite communications.

(3) Real-time excavation control and work progress control was both able to be carriedout through the automatic surveying system comprised of a GPS and an automatic total follow-up station linked to the computer graphics of heavy construction equipment.

(4) By freely using virtual-reality technologies which realize three-dimensionally-operated displays, the sounds generated by construction equipment, and computer graphics, the remote operation of construction equipment on the computer display could be carried out.

(5) The construction equipment was able to be protected from mechanical failure, due to the computer display in the control room, into which maintenance information of the construction equipment was input at real time.

3. SYSTEM'S POINTS AT ISSUE AND COUNTERMEASURES

While ensuring the thorough functioning of the Tele-Earthwork System, various issues arose. We addressed these issues in turn as discussed below in order to create the same operational environment as that by a manned operation.

Table 1.
Points at issue and countermeasures

No.	Point at issue		
	Item	Detail	Countermeasure
1	Communica-tion system	o Mobile and rotational folow-up of the communication system. o Protection of the electric wiring.	o Follow-up could be realized by installing rotary stands, universal joints and the use of slip rings.
2	Heavy and light universal heads	o Labor-saving to be effected by enabling wireless units to oppose each other. o Making the heads more robust.	o A heavy universal head with four heads incorporated in it was manufactured. Heavy-duty universal heads were manufactured as well.
3	Universal camera head	o To protect cameras during travel.	o Provisions were made so that cameras be fixed and retracted.
4	Crawler dump truck	o Vessel reinforcement. o Software modification. o Prevention of the shaking.	o Reinforcement was provided to resist the impact caused by falling rocks. o Provisions were made so that crawler dump trucks start to travel only after the vessel has been seated in place. o Stopper guides were installed.
5	Vibration isolator	o Protection of communication units and control panel.	o Silicon-rubbered isolators, Ever-Mount rubbered isolators, isolating pads or air dampers were provided wherever necessary.

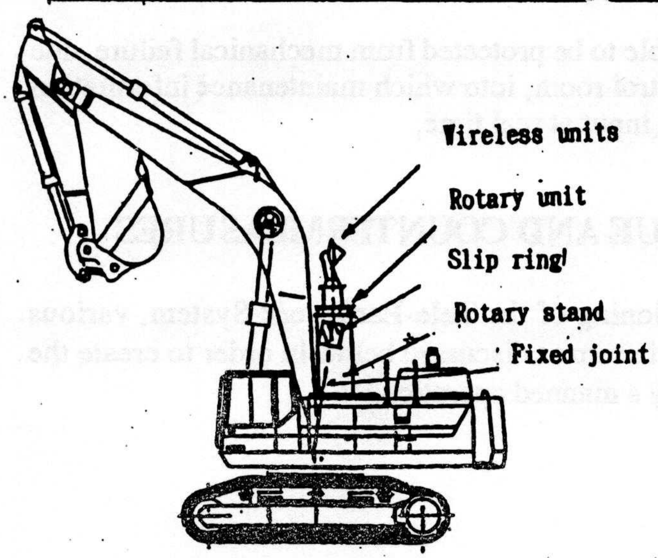

Figure 2. A modified hydraulic shovel.

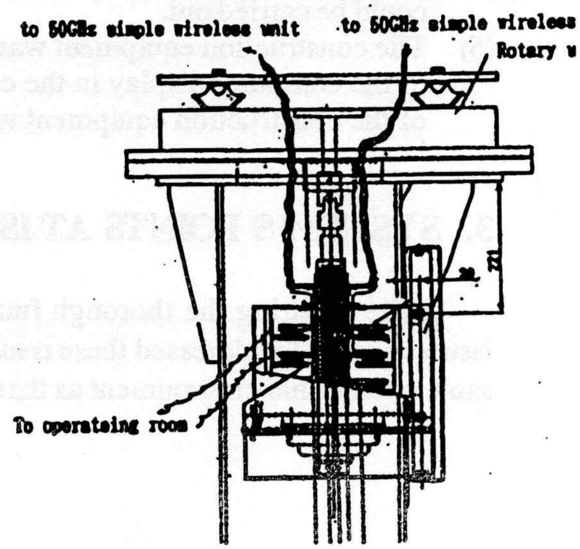

Figure 3. Detail of a slip ring.

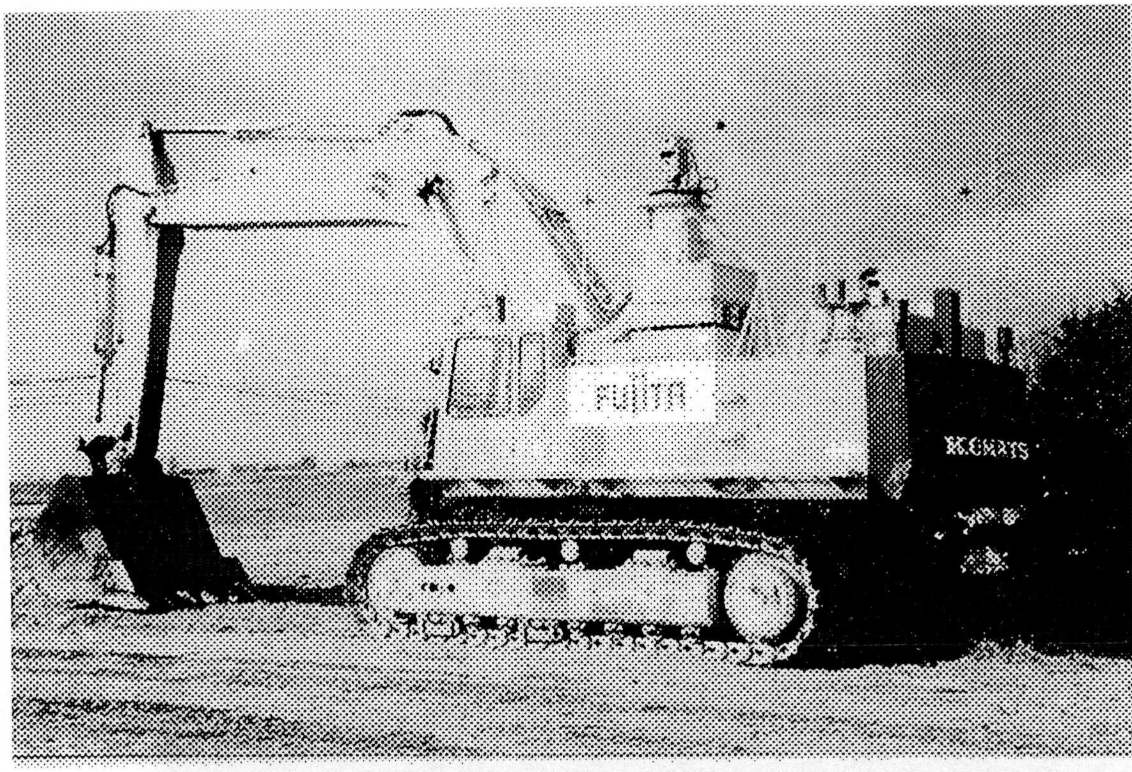

Photo 1. A hydraulic shovel performing construction.

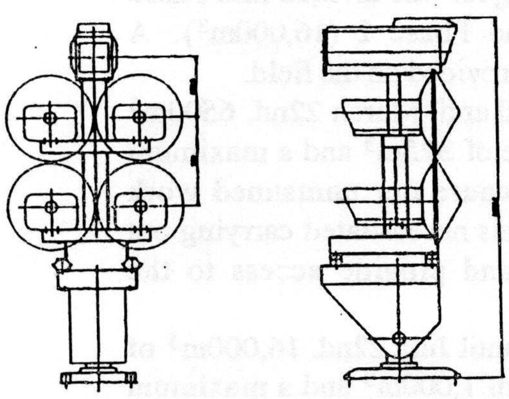

Figure 4. Detail of a heavy universal head.

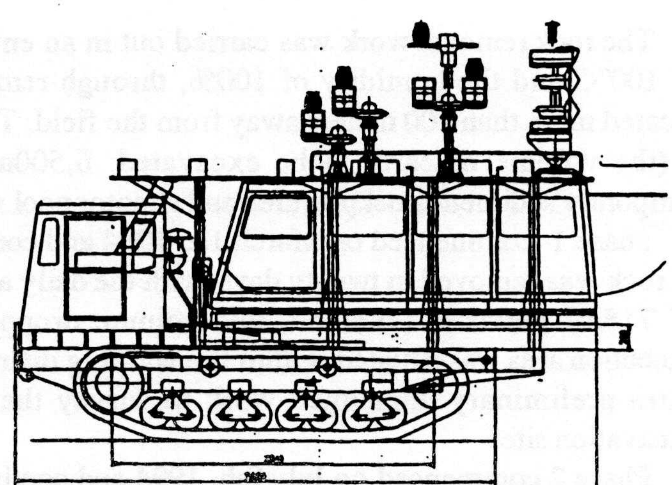

Figure 5. Detail of a universal cam head.

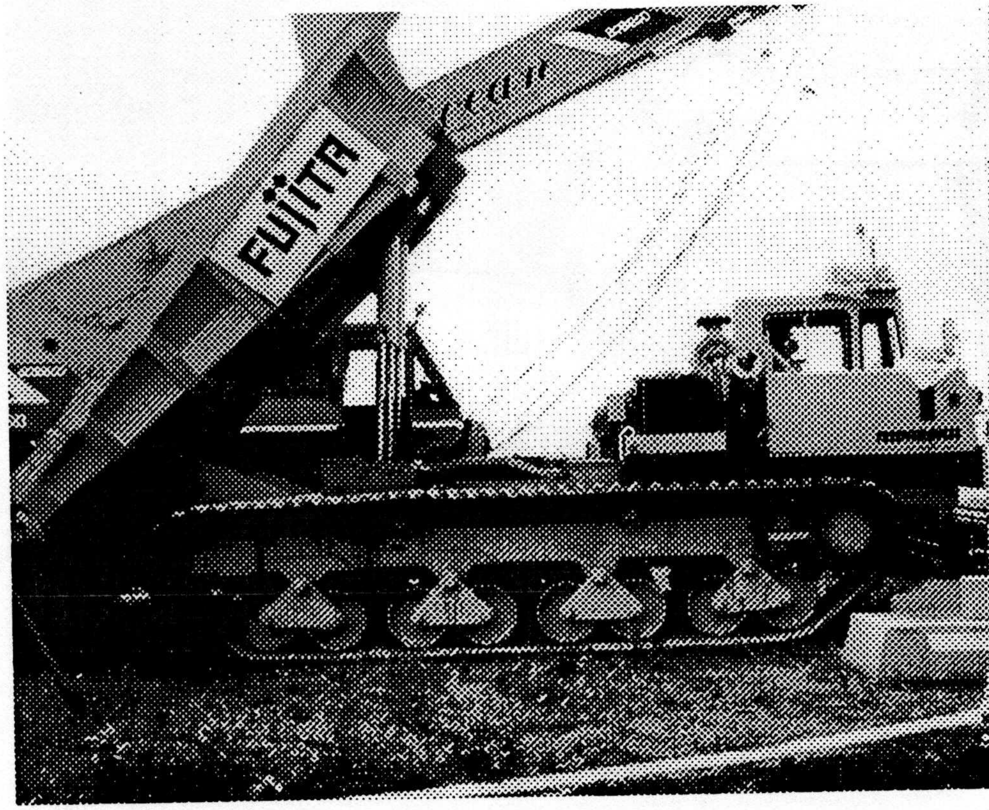

Photo 2. A crawler dump truck performing the assignment.

4. EXECUTION ACHIEVEMENTS

The rock removal work was carried out in an environment having the temperature of 100°C and the humidity of 100%, through remote control conducted at a place located more than 100 meters away from the field. The project was divided into Phase 1 (the volume of earth to be excavated: 6,500m^3) and Phase 2 (16,000m^3). A temporary sediment stockpile area and a motor pool were provided on the field.

Phase 1 commenced on March 1st, 1994 and continued until March 22nd. 6500m^3 of rock was removed in twenty days, with the daily average of 325m^3 and a maximum of 715m^3 per day. Later on, this volume dropped because our unmanned work execution area was situated within the warning district. This necessitated carrying out extra preliminary unmanned work to survey the site and provide access to the excavation site.

Phase 2 commenced on July 8th, 1994 and continued until July 22nd. 16,000m^3 of rock was removed in sixteen days, with the daily average of 1,000m^3 and a maximum of 1,518m^3 per day.

After checking the functions and maneuverability of the communication systems and the heavy unmanned construction equipment it became possible to verify that the ultra remote operation through the Tele-Earthwork System is feasible. A control room was provided downstream at a point approximately two kilometers away from the work area.

Through pictures, voices and sounds transmitted all the way from the unmanned work execution area, the plural of heavy unmanned construction equipment carried out a series of earthwork including excavation, loading and transportation to disposal. All through these operations, the communication performance of the communication systems and the maneuverability of the unmanned heavy construction equipment could be assured.

Photo 3 shows the overall view of the unmanned construction equipment performing the assignments.

The practicality of the remote communications and remote operations conducted from a distant point of some two kilometers, and the maneuverability of the unmanned heavy construction equipment, were able to be well proven. We believe these achievements will surely contribute to laying the future foundation for a further improved Tele-Earthwork System.

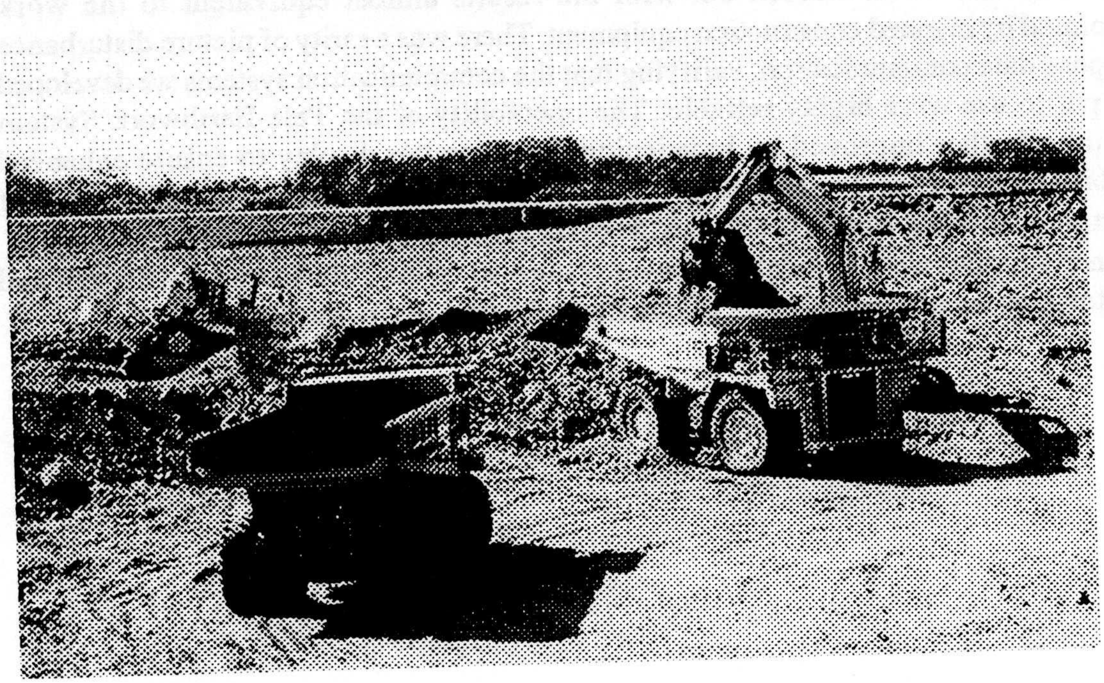

Photo 3. Overall view of unmanned construction equipment performing the assignments on the field.

5. FUTURE IMPROVEMENTS

Including the following targets, we will deliberate on various points in order to create a further improved version of the Tele-Earthwork System which has been discussed so far in this paper.

(1) An improved maneuverability of unmanned construction equipment through remote operation.
(2) An improved mobility of unmanned construction equipment and more simplified systems.
(3) A more effective arrangement of picture monitors.
(4) A more effective arrangement of communication radios.
(5) Improved vibration isolation.
(6) Improved heat resistance.

6. CONCLUSION

This unmanned work execution experiment that we carried out was the first of this kind in the world. There were a number of technical issues that arose that we had never experienced before, but nearly satisfactory achievements resulted. Remote-operated work was able to be carried out with the results almost equivalent to the work performed by manned construction equipment. There was a rarity of picture disturbance and poor data communication, verifying that the communication systems we developed and put to use were highly reliable. The operability of the Tele-Earthwork System could be further improved by broadening the computer display to ensure enhanced legibility as well as by installing a greater number of cameras. The efficiency of executing the work was within the range of 40 to 80% depending on the condition.

In the future, we will heighten the completeness of the Tele-Earthwork System and aim towards the accomplishment of full-fledged unmanned construction.