Development of Virtual Survey Marking System (VSMS) for Remote Control of Construction Machinery

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ABSTRACT

Remote control technology for construction machinery is attracting attention because it can permit construction work to be conducted safely in dangerous areas or in such special environments as are encountered when developing deep underground spaces. If remote control of construction machinery is necessary, this means that survey workers cannot enter the area and accordingly makes it impossible to set the necessary markers such as batter boards and posts, which in turn reduces the efficiency and accuracy of excavation work. Solving this problem has long been a major task to be accomplished in order to achieve practical remote control of construction machinery.
A system has been developed to solve the problem. The system creates a realistic three-dimensional (stereo) image of the work area by combining images of the work area acquired from a camera used for remote control and computer-generated images of reference marks such as batter boards and posts. This paper outlines the system and reports the results of validity tests of the system.

1. INTRODUCTION

To improve the safety of construction work, a variety of research and development is being done on technology for remote control of construction machinery[1, 2].
In the process of civil engineering work, excavation locations, gradients for soil cutting and heights for banking are conventionally determined beforehand using survey information and are marked with batter boards and posts. However, in a dangerous area or in a special environment where remote control of construction machines is imperative, the fact that surveyors cannot work in the area is likely to reduce the efficiency and accuracy of the work because of the lack of reference marks.
In response to public desire for disaster prevention measures at dangerous areas near Mt. Fugen in Unzen, which erupted in 1990, machines were operated by remote

control to perform work in the area and to test their feasibility. This was the first case in which the Test Field System institutionalized by the Ministry of Construction was applied. Remote control work continues there, to achieve the goals safely. Better efficiency and accuracy are strongly desired for this sort of work.
For these reasons a system called the Virtual Survey Marking System (VSMS) was developed. The system shows the operator virtual reference marks such as batter boards and posts by means of computer graphics.

2. OUTLINE OF THE SYSTEM

The system displays a realistic three-dimensional (stereo) image of the work area along with virtual reference marks such as batter boards and posts, by combining images acquired by a camera installed on a construction machine for remote control purposes with computer-generated images of reference marks.
As illustrated in Figure 1, the system consists of a stereo camera, a virtual reference mark formation block, an image synthesis block and a stereo image display block. An operator operates a construction machine by remote control from the remote control room, observing the display on the monitor in the stereo image display block. The following outlines the creation of virtual reference marks and the stereo image display block, which are central to the system.

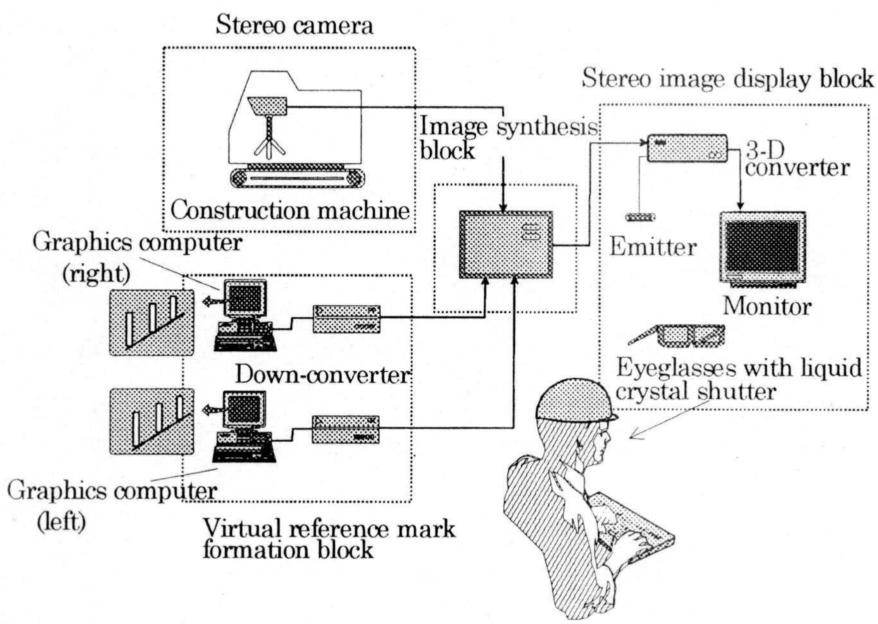

Fig.1 VSM System Blocks

2-1. Virtual reference mark formation block

Images of virtual reference marks such as batter boards and posts can be generated by computers using coordinate data on the location of excavation, soil cutting or banking obtained from working drawings, and the position, attitude and image acquisition range of the stereo camera. The virtual reference mark formation block generates two images of each virtual reference mark, one for the left eye and the other for the right eye, each being generated by a dedicated computer. In the same manner as the images of a stereo camera, each image is given parallax and is converted into NTSC video signals.

2-2. Stereo image display block

The stereo image display block displays images which combine virtual reference marks and images of the work area acquired by a stereo camera. The high speed 120-Hz liquid crystal shutter eyeglasses produce good images of uniform quality.

Table 1 VSM System Specifications

Item	Specifications
Stereo camera	410,000 pixel CCD cameras(2),f=8.5mm-51mm
Virtual reference mark formation block	PC9821-Xs (2),NTSC output image
Synthesis block	2:1 interlace field allocation
Stereo image display block	120Hz liquid crystal shutter switching, 21 inch monitor

3. BASIC PERFORMANCE CONFIRMATION TEST

To understand the basic performance of the system, its usefulness for positioning construction machines was tested with a hydraulic breaker type hydraulic shovel in the 1.6-m^3 class.

3-1. Test method

In the test, remote control was exercised over the shovel by making use of images acquired by a stereo camera installed in the operator's booth of the shovel. The binocular parallax of the camera was set to become zero at a distance of 8.5 m from the camera, and the zoom of the lens was set at its widest angle. This was done because making the image acquisition range as wide as possible is always favorable to improving the efficiency of work done by remote control.

Four virtual reference marks for positioning the shovel breaker were set at intervals of 2 m, as indicated in Figure 2, from 4.5 m to 10.5 m from the camera. The front end of the shovel breaker was then operated by remote control to aim and position it at each mark, after which the distance between the front end of the shovel breaker and the mark was measured. In addition, to evaluate the relative performance of the system, it was tested in other ways as described below.

(1) Manned shovel test: the breaker was positioned at an actual batter post while the shovel was operated by an operator on board.

(2) SMS test: the breaker was positioned at an actual batter post while the shovel operated by remote control.

(3) VSMS test: the breaker was positioned according to a virtual mark with the shovel operated by remote control.

Since red tends to create a feeling of nearness and blue a feeling of distance, green (which is an intermediate wavelength) was adopted for the virtual reference mark and the actual batter post.

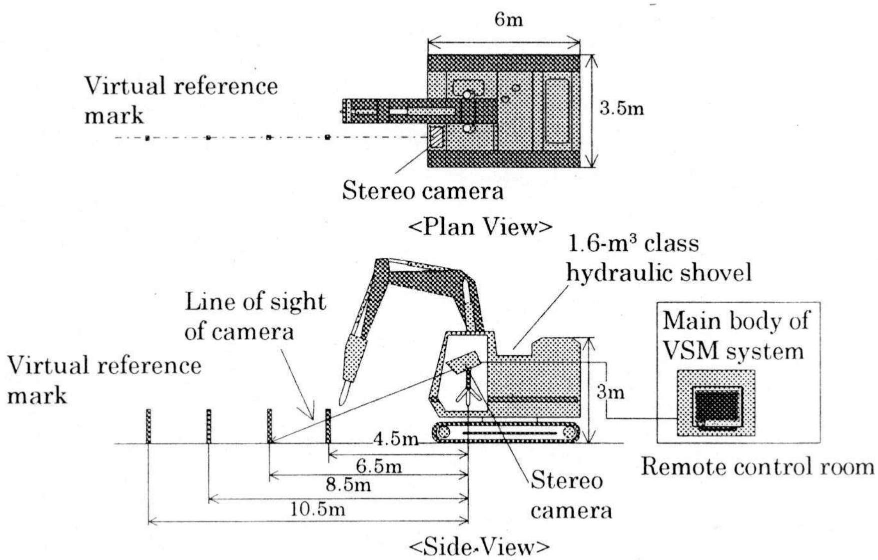

Fig.2 Test Method

3-2. Result

Figure 3 shows the averages of distance errors made in ten attempts to position the breaker at a mark for each test.

From the figure, the following are clear.

(1) Manned shovel test: The breaker was positioned with distance errors of about 0.1 m from actual batter posts located within 8.5 m of the operator's seat, but distance error increased to about 0.8 m when the breaker was positioned at actual batter posts 10.5 m from the operator's seat.

(2) SMS test: The distance error in positioning the breaker became larger as the distance from the camera (at the operator's seat) to the batter posts increased.

(3) VSMS test: The distance error in positioning the breaker was about 0.1 m regardless of the distance between the camera and the batter post represented by a virtual reference mark.

Comparison of the results of the VSMS and SMS tests, in both of which the shovel was operated by remote control, indicates that VSMS allowed smaller errors than SMS for every distance between mark and camera. In the SMS test, both the color and the shape of the image of the batter post displayed on the monitor faded as distance between camera and post increased. But, in the VSMS test, the displayed image of the virtual reference mark remained clear regardless of the distance.

On the other hand, comparing the result of the VSMS test with that of the manned shovel test reveals that manned operation allowed better positioning when the batter post was not far from the operator's seat. But, at farther positions, the best results were obtained using VSMS. This indicates that a distance greater than about 10 m between batter post and operator is difficult for the operator to perceive correctly, even if the operator is present on the machine.

The foregoing demonstrates that the VSMS system is useful for positioning a shovel at an intended spot, and that the system can be applied to excavation and crush work that requires shovels to be operated by remote control.

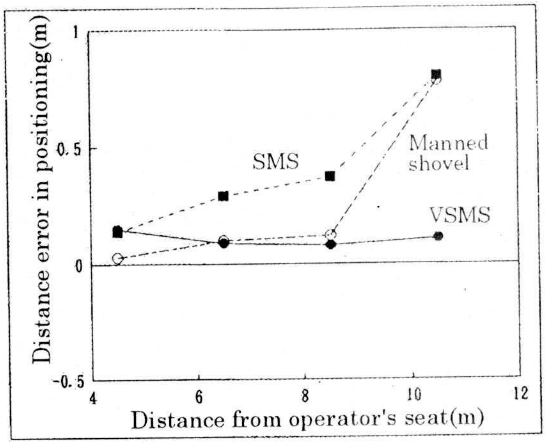

Fig.3 Breaker Positioning

4. EXCAVATION TEST

In order to evaluate whether this system can be applied to actual work, an excavation test was performed with a hydraulic shovel of the 3.8-m^3 class at a site near Mt. Fugen in Unzen where stone was being removed and no people could enter.

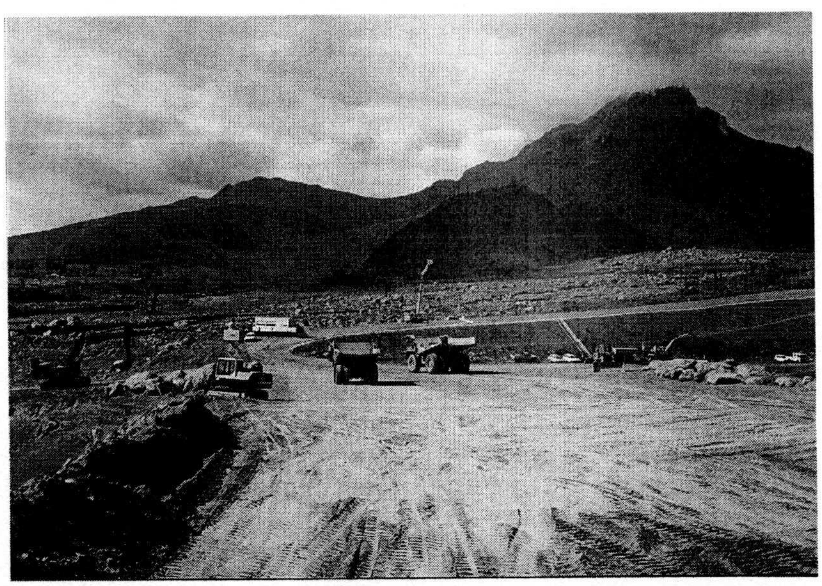

Photo 1 Work at Mt.Fugen

4-1. Test method

The hydraulic shovel was operated by remote control as the operator viewed an image of the site acquired by a stereo camera installed on the shovel. The binocular parallax of the camera was set to become zero at a distance of 8.0 m from the camera, and the zoom was set at the same angle as in the basic performance confirmation test. As illustrated in Figures 4 and 5, two excavation sections were established: section 1, between 5 m and 8 m distant from the camera on the shovel; and section 2, between 8 m and 11 m distant from the camera. The excavation depth was to be 0.8 m in both sections. Virtual reference marks were shown at both the starting and ending points of the excavation with their heights from the ground surface set at 0.8 m, the same value as the excavation depth, in either section.

After the excavation, the cross-section of the excavation (shown in Figure 5) was measured.

In order to evaluate the relative applicability of the system, excavation tests were conducted with actual batter posts instead of virtual reference marks as follows.

(1) SMS test: excavation was conducted by referring to actual batter posts while the shovel was operated by remote control.

(2) VSMS test: excavation was conducted by referring to virtual reference marks while the shovel operated by remote control.

In this test, as in the basic performance confirmation test, green was adopted for the color of virtual reference marks and actual batter posts.

Photographs 2 and 3 are scenes of the test.

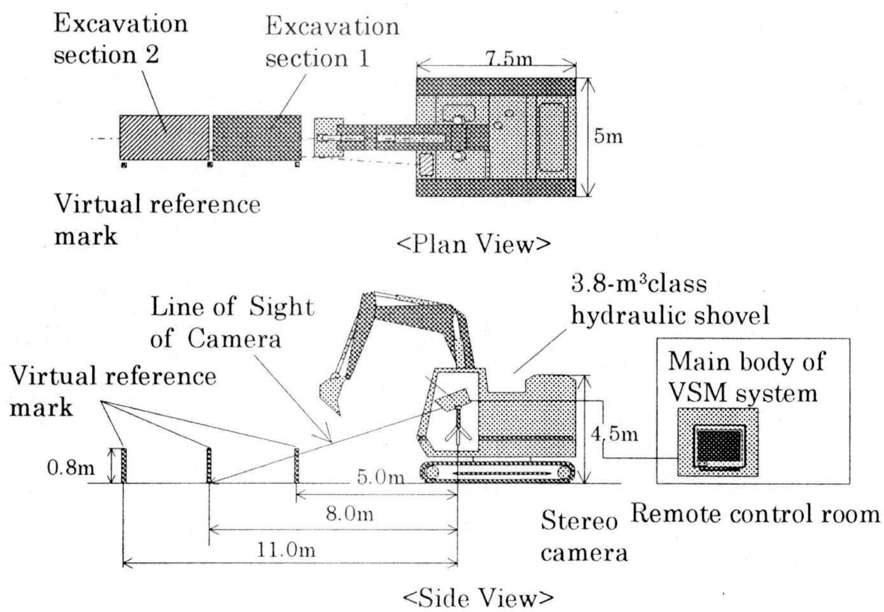

Fig.4 Test Method

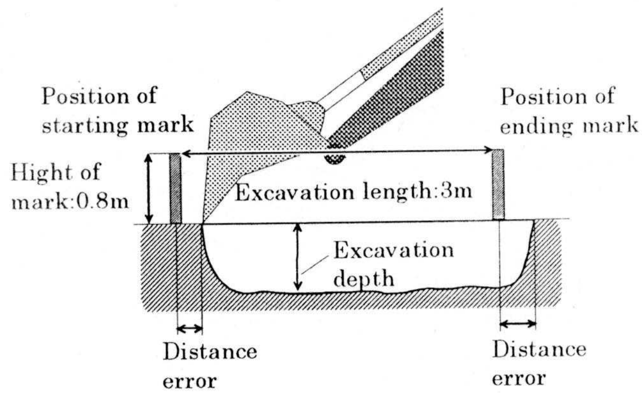

Fig.5 Excavation Method

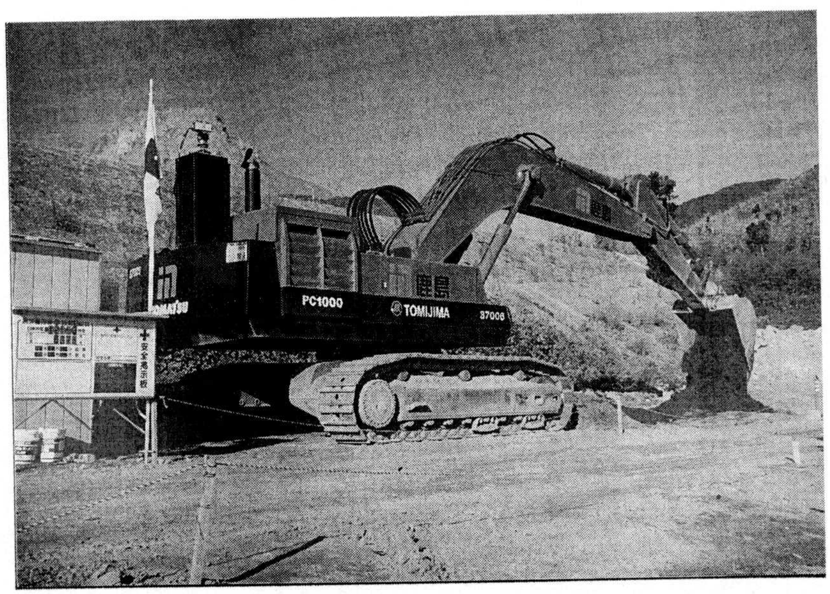

Photo 2 Excavation Test

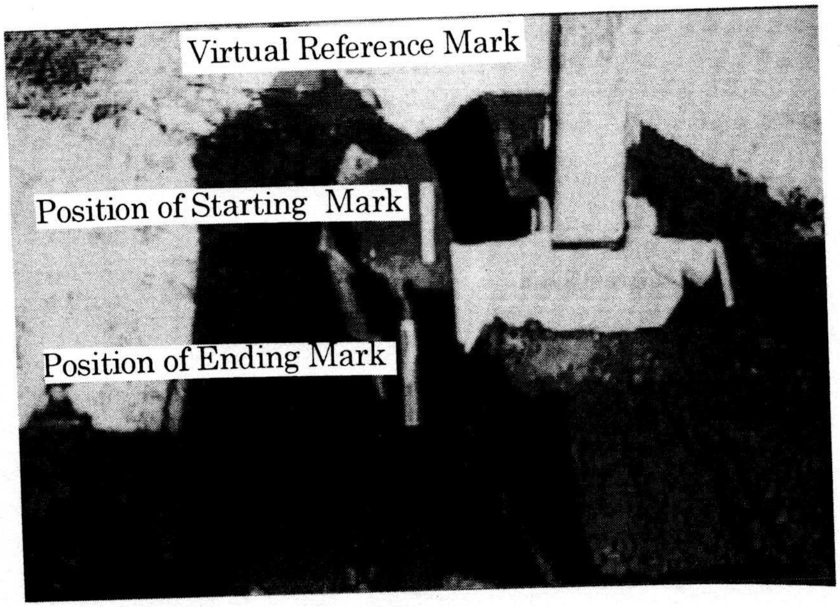

Photo 3 Virtual Reference Mark Display

4-2. Results

Figure 6 shows the result of distance error measurements for four excavation trials at the two sections. The following can be understood from the figure:

1) In both sections, VSMS allowed smaller distance errors (measured from the virtual excavation starting marks) than did SMS. SMS allowed distance errors about 0.5 m outward from the targeted starting posts in both sections. This concurs with the result of the basic performance confirmation test, in that SMS allows greater distance errors in positioning the shovel outward from the targeted starting post than does VSMS.
2) In section 1, both VSMS and SMS allowed larger and more dispersed distance errors in positioning the shovel bucket near the ending mark than the starting mark. This is because the bucket was positioned in the same manner as in the basic performance confirmation test while working near the starting mark, but near the ending mark the operator referred to the excavation ending mark while the bucket was in the soil as the excavation was still in process, making the ending mark more difficult to recognize than the starting mark.
The distance errors the VSMS allowed were smaller than those allowed by the SMS.
3) Distance errors near ending marks were smaller in section 2 than those in section 1. This is because the 3.8-m^3 class shovel used in the test was too large for the operator to perform delicate actions for a mere 5 m away as in section 1. VSMS allowed smaller distance errors at ending marks than did SMS, particularly outward from such posts.

Figure 7 indicates the result of excavation depth measurement in each section. In both sections, the excavation done with VSMS was about 0.05 m shallower and the excavation done with SMS about 0.1 m deeper than planned. Considering that the bucket of the shovel measured 2 m tall, the difference between the results achieved with VSMS and SMS is slight.

Displaying excavation depth as height of the starting mark was effective, as the operator could judge how deep to excavate by comparing the height of the mark with the height of the shovel bucket.
This test proved that the system makes it possible to do excavation work using a shovel operated by remote control with adequate accuracy.

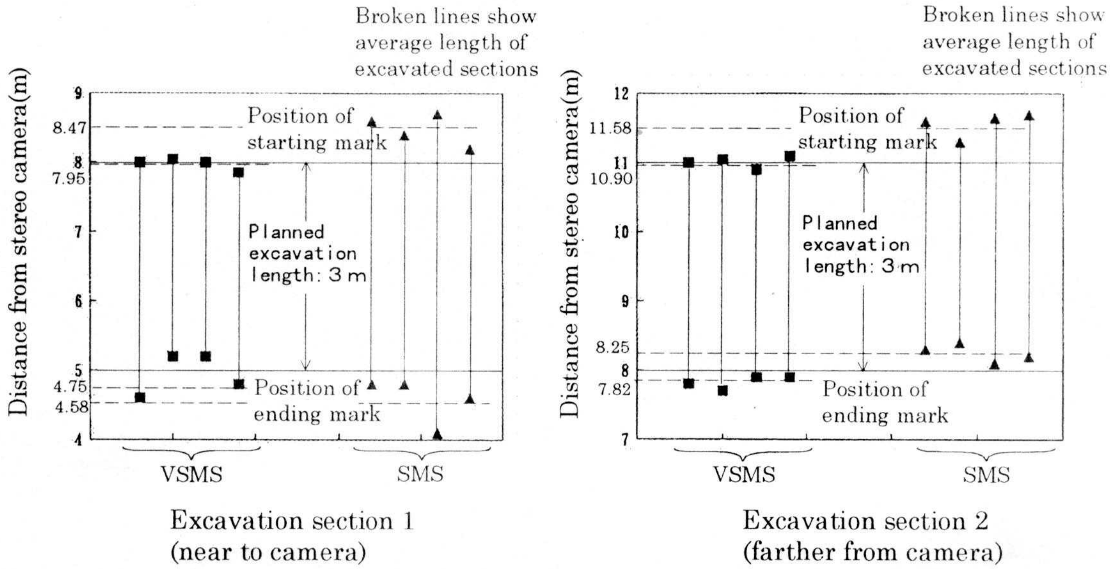

Fig.6 Comparison of Excavated Ranges

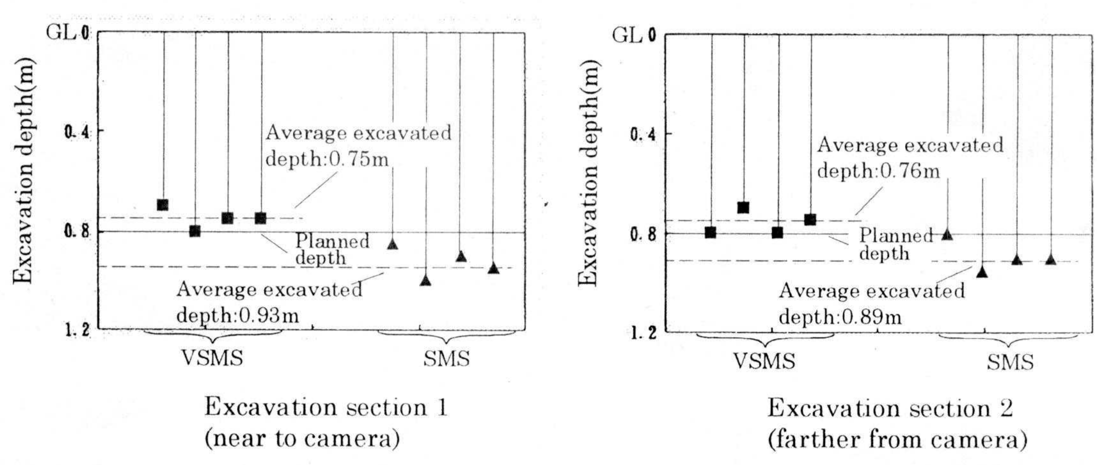

Fig.7 Comparison of Excavated Depth

5. CONCLUSION

VSMS was developed to improve efficiency and secure accuracy in remote control work with construction machines. The system can indicate an excavation position or a soil cut gradient in the form of a virtual reference mark. Tests in which work was done by an operator referring to the marks proved that the system allows excavation with distance errors of about 0.1 m in position, and accordingly proved that the system is suitable for use in excavation work that requires machines to be operated by remote control.

In the future, we will refine the system and put it to practical use.

6.REFERENCES

1) Shimoda; "Kajima•EX•Tele-Con-System", Kensetsu no Kikaika, No. 534, 25-29, August, 1994.
2) Komoto and Sakuma; "Automated Caisson Technology", Construction Machinery and equipment Vol. 26, No. 11, 41-47, 1990.