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Development of tunnel face marking system

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ABSTRACT

We have developed face marking system (named tunnel marker) using for tunnel construction. This system is composed with laser projector, total station, tripod, controller and surveying mirror.

It can intermittently project following items to the appointed place from optical located position in the tunnel. This operation is by wireless.

① Center point of the tunnel
② Center line of the tunnel
③ SL diameter
④ Excavation line
⑤ Drilling position (for smooth brushing method)

This projection is stationary image and projectable distance is about 100~300m with face intensity of illumination 150~300 lux.

Projection accuracy is equivalent to total station accuracy in center point of the tunnel using adjustment control. Besides: As coordinates of road (X, Y, Z) is taken for control of projector, this system makes the works easy under construction (i.e., not only indication of drilling position and excavation line also built-in steel support, control of excavation for tunnel center line of curve process etc.)

INTRODUCTION

Marking on the face is required in tunnel construction in general for positioning steel supports basement, indicating the tunnel centerline for forming a curve, indicating bedrock excavating lines for non-steel support sections, and positioning drill holes for blasting. These marking has conventionally been performed by using special gages, bars and strings after finding the tunnel center with a pair of reference lasers installed behind the work place (100 to 200 meters behind the face). In spite of the cost of a tremendous amount of manpower and time, the net results were, work inefficiency and defective positioning accuracy, and it has been necessary to allow for extra amounts of shotcrete and concrete lining.

The newly developed tunnel face marking system (named tunnel marker) is able to mark the face more accurately and more quickly using a laser beam projection system. It features both survey and laser beam projection functions. The tunnel marker is capable of performing the following jobs, and the projecting patterns are selectable via a wireless control system according to work requirements.

① Displays tunnel center (point)
② Displays tunnel centerline (radius: five quartered points)

③ Displays position of steel supports assembly (SL dia.: nine 8-division points)
④ Displays peripheral lines for the cross section of the excavation (circle, ellipse: 10-degree pitched points)
⑤ Displays position of side hole and relief hole for blasting (double circle or double ellipse: circular arc points of any division)

Tunnel marker projection distance is 100 to 150 meters for face illuminance of 150 to 300 lux. Projection accuracy is approx. ±10mm at the tunnel center for a projection distance of 70m (before adjustment).

This paper introduces the tunnel marker system and reports the results of on-site tests.

2. SYSTEM OUTLINE

The tunnel marker is a mechanical system which projects the tunnel center point on the face to be excavated by the inputting of road coordinates (X, Y and Z) (positioning and survey function) data. It also displays excavating lines, drilling positions, etc. using the specified dimensions (laser graphics function). Projected images are controlled by a controller. Photo 1 shows the system structure.

The survey unit consists of a total station, two reflecting mirrors, and a survey computing unit. It determines the positional coordinates of the tunnel marker which is installed in a random place with reference to an actual survey point (dowel), and determines the direction angle and the distance of projection (aslant) to the tunnel center on the basis of road coordinates.

The projecting unit comprises a laser projector and a projected images controller. It is designed to project images of a specified size according to the distance of projection determined by the survey.

Table 1 shows the specifications of the tunnel marker.

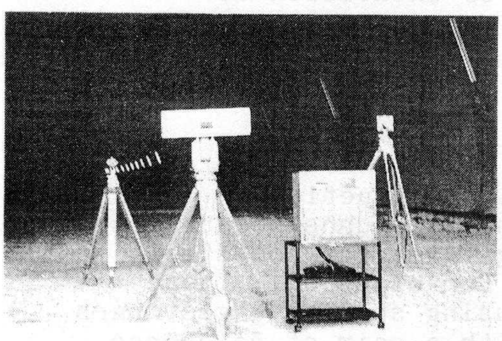

Photo 1 System Structure

Table 1 Specifications

Power source		AC100V, 50/60Hz
Laser	Oscillating wavelength	6328Å
	Oscillating output	10mW
Projection patterns	Line width	10mm/100m min.
	Spread width	±24° max. (continuously variable)
	No. of patterns available	Five (point, radius, dia., circle/ellipse, double circle/double ellipse)
	Rotational speed	Infinitely variable
Total station		10-seconds reading
Coordinates used		Road coordinates (S, Y, Z)

3. PROJECTOR

The projector consists of a laser (He-Ne) and a scanner with two reflecting mirrors (X/Y and Z axes). A single laser beam is controlled by the two mirrors to display excavating lines, drilling points, etc. on the face as continuous points. Photo 2 shows the structure of the projector.

The laser beam, stroked the X/Y-axis mirror B and the Z-axis projecting mirror C via the reflecting mirror A, projects the image on the face by their swing.

The swinging is dictated by the scanner, the swing angle of mirrors varies in accordance with the electric current changed by the controller, and the required line projection and its move is available.

In the actual operation of the system, an image projected on the face must be moved depending on the situation. For this reason, the projected image can be moved vertically or horizontally by parallel translation. In addition, parallel translation is used to adjust the origin of the first projection (adjustment of a subtle difference between the optical axes of total station and projector), thereby setting the reference for the scanner's swing angle (see Fig. 1).

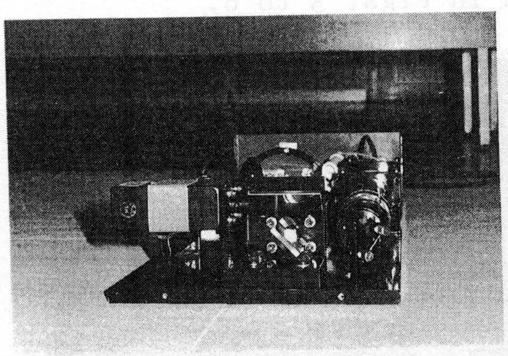

Photo 2 System Structure

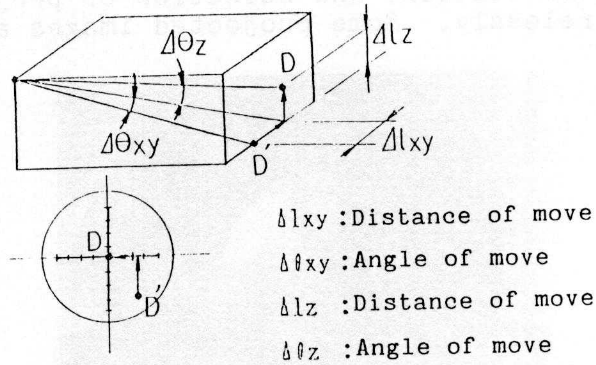

Fig. 1 Origin Adjustment for the Marker (Parallel Translation)

4. PROJECTION (Face Marking)

(1) Projection of Tunnel Center Point

Typical positional relationship between functional units in the setting up of the tunnel marker on an actual construction site is shown in Fig. 2.

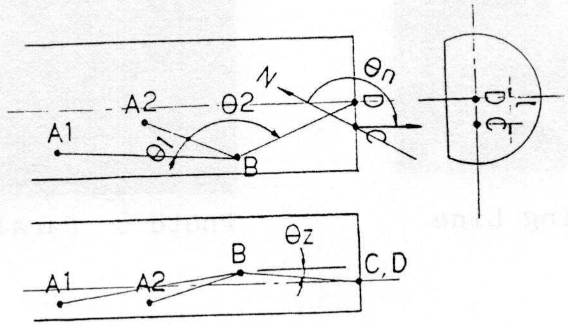

Fig. 2 Positional Relationship and Projection of Tunnel Center Point

Using the total station of tunnel marker which is installed at a proper place within a tunnel, the positional coordinates of the tunnel marker will be available by surveying the distance, angle, and the height of two surveyed points (A1 and A2). Besides, positional coordinates for the tunnel center point (D) were determined using the coordinates of the center point of the tunnel road (C) and the tunnel face advance angle (θn). Further, horizontal and vertical projection swing angles (θ2 and θz) were determined by the positional coordinates of the tunnel marker (point B) and the tunnel center point (D).

(2) Projected Images

There are kinds of images that has to be displayed on the face, such as, tunnel centerline, SL dia., excavating lines, and drill positions.

The projection of these images is obtained by the following process. First, the scanner swing angle (θs) is extract from the slant distance and the dimensions of the projection (radius, dia.) determined from the coordinates of points B and D, and then either Z-axis mirror (center line) or X/Y-axis mirror (SL dia.), otherwise both of them (excavating line, drilling position) swing at the specified swing angle (θs).

Adjustment of optical axes in the projection of tunnel center point (adjusting control to agree the laser beam with the alignment line of the total station) and selection of projected images are performed wirelessly. Some projected images are shown in Figs. 3 to 6.

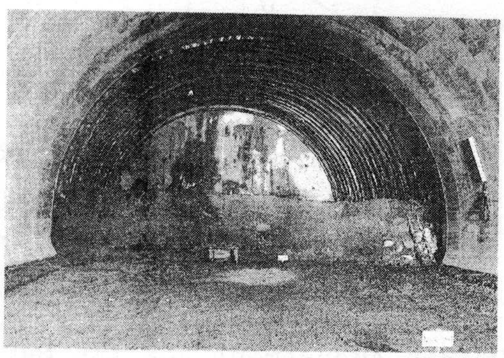

Photo 3 Tunnel Centerline

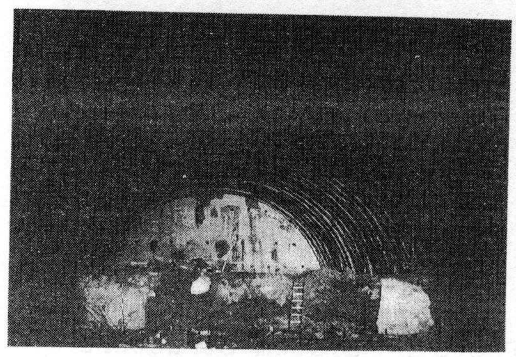

Photo 4 SL Dia.

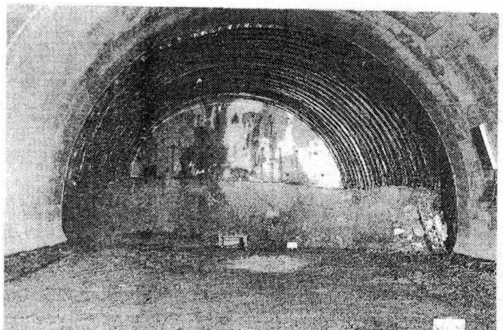

Photo 5 Excavating Line

Photo 6 Parallel Translation

5. RESULTS OF ON-SITE TESTS

On-site tests of the tunnel marker were conducted in the following construction sites, Aioi No. 2 Tunnel (short bench method) and Mt. Kasai West Tunnel (mini-bench method).

In the initial construction stage, all projections were performed by line projection (continuous straight lines, continuous circular arc lines, and 3-division circular arc lines), which were then replaced with the intermittent point projection for the following reasons:

① Projected images were difficult to be recognized on the face, and the projection distance was approx. 30 meters, which was too short (illuminance at the face: 150 to 300 lux).

② Circular arc lines were distorted due to face unevenness resulting from blasting, and the system was not suitable for displaying excavating lines.

Intermittent point projection was performed after investigation, with the result that the distance of projection was increased to as much as 300 meters at maximum, and excavating lines and others were clearly recognized in spite of uneven faces. Thus, this method was adopted.

In addition, in the mini-bench method, excavating lines for the lower half section were necessary. For this reason, the initial semi-circular arc projection was replaced by the system shown in Fig. 3, so that the system might be used in both the short bench and mini-bench methods.

Further, anticipating nighttime excavations, coordinates of respective face were input beforehand, which were then called by wireless operation, to project proper images in accordance with the specified face. This type of projection is realized by changing the tunnel center point to the predetermined amount using the scanner, rather than swinging the total station itself. Photo 7 shows the condition of an excavation work using projected excavating lines.

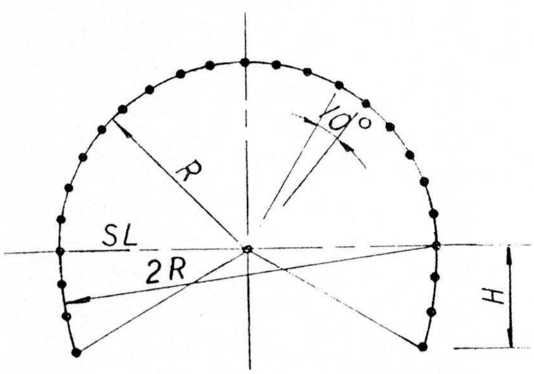

Fig. 3 Excavating Lines Used in the Mini-Bench Method

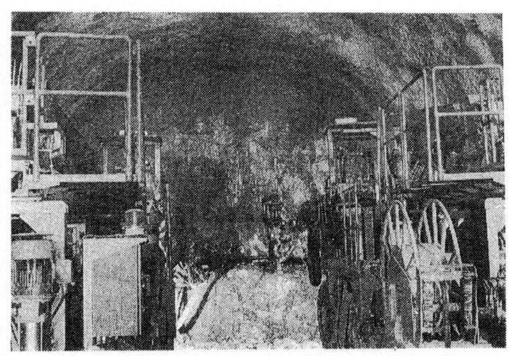

Photo 7 Condition of Excavation Using Marking

6. CONCLUSION

More than five years have passed since we started the development of the tunnel face marking system. Today, the construction industry is experiencing aggressive automation and labor-saving efforts heretofore never seen. In the field of tunnel construction, various technological subjects exist including the face marking system. The tunnel marker represents one of these technological subjects. Even though it is not accomplished yet, we shall be very glad if the present report will be of some help for the improvement in tunnel construction work.

Blasting technology on site finally depends on site workers' sense and experience because of the rock quality difference, but the tunnel marker which we have developed is designed to be a partner which contributes to automation and labor-savings in tunnel construction.

Finally, we would like to appreciate those people in and outside our company who have given us valuable cooperation in the development of this system.