Analysis on shield operational parameters to steer articulated shield

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ABSTRACT

Nowadays, articulated shield becomes popular to construct tunnels with curved alignments. To steer the articulated shield, it is necessary to determine the operation on jack, copy cutter and articulation mechanism. But since these three functions have a high co-linearity to shield behavior, it is difficult to obtain unique operational parameters at once. Therefore, the authors developed a numerical method to determine the copy cutter length and the articulation angle uniquely, based on geometric conditions under some constraint conditions. This paper shows an example of the application of the proposed method to a 3 dimensional compound alignment and discusses the validity of the proposed model. As conclusions, the followings were found: 1) the articulation angle depends on shield dimension, tunnel alignment and operation rules of shield rotation; 2) the copy cutter length distributes across the major normal direction of the tunnel about a half of the skin plate area; and 3) the analysis results demonstrate that the proposed method can provide articulation angle and copy cutter length and range reasonably from the view point of geometric conditions.

Keywords: shield tunnelling, articulated shield, copy cutter, articulation angle, steering method

1 INTRODUCTION

Shield is operated for excavation, steering shield, filling up in tail void, and segment installation mainly. As for steering shield, shield is controlled by jack, copy cutter and articulation mechanism in practice. The jack generates thrust and horizontal and vertical moment, which can be determined by jack pattern and shield jack pressure. The copy cutter can carry out overcutting with a specified depth and a specified range along the circumference of cutter face. The overcutting by copy cutter defines excavation area and reduces ground reaction force at the overcutting range, which makes the shield rotate toward the overcutting range easily. The articulation mechanism for articulated shield (Maidl et al., 2012) can crease shield with a specified direction and a specified angle. The crease of shield can reduce ground reaction force at curves by fitting the shield for its excavation area, which makes the shield rotate easily.

In the previous researches, there are two ways to simulate shield behavior. First one uses a relationship between shield attitude and jack moment by obtaining the unknown parameters in the model statistically. Shimizu and Suzuki (1992) proposed a relationship between the change of shield attitude and the jack moment and examined it based on the site data and the measured data of the model tests. Sakai and Hoshiya (1987, 1993) proposed a method to identify the unknown parameters in the formulation of Kalman filter technique and examined it based on site data. On the other hand, second one uses a kinematic shield model based on equilibrium conditions, considering the jack status, the use of copy cutter and the use of articulation mechanism (Sugimoto and Sramoon, 2002). This paper was pointed out that the gap between excavation area and shield skin plate is a predominant factor to influence shield behaviour.

Therefore, in order to steer shield, it is necessary to determine the operation on the jack, the copy cutter and the articulation mechanism. But since these three functions have a high co-linearity to shield behaviour, it is difficult to obtain unique operational parameters at once. Then the authors developed a numerical method to determine the copy cutter length and the articulation angle uniquely, based on geometric conditions under some constraint conditions (Chen, 2008). This method can consider straight, circular and clothoid curved alignments on horizontal plane and straight, circular and parabolic curved alignments on vertical plane. Furthermore, this method can deal with horizontal curved alignment and vertical curved alignment at the same position, which is named 3D compound alignment. After determining the copy cutter length and
the articulation angle, the jack force is calculated, based on equilibrium conditions.
This paper shows an example of the application of the proposed method to a 3D compound alignment and discusses the validity of the proposed model.

2 METHODOLOGY

2.1 Calculation conditions
The numerical method used the following conditions based on site experience:
1) The center of segment end, P_{CSE}, follows the planed tunnel alignment;
2) The axis direction of rear body, r_2, is the tangential direction of the planed tunnel alignment at P_{CSE};
3) Articulation angle is determined so that copy cutter length used at the convex side of curve is minimized; and
4) Copy cutter range and length are determined so that shield body does not push the ground, that is, shield exists inside the excavated space.

2.2 Classification of machine type
From the view point of geometric conditions, shield machine are classified into three types according to the maximum length among L_1, L_{CSE}, and L_2, as shown in Table 1. Here,

\begin{align*}
  L_1: & \quad L_{M1} - L_{CSE} \\
  L_2: & \quad L_{M2} - L_{CSE} \\
  L_{M1}: & \quad \text{Length of front body} \\
  L_{M2}: & \quad \text{Length of rear body} \\
  L_{CSE}: & \quad \text{Length from crease center to segment end plane}
\end{align*}

And these are shown in Fig. 1.

On the other hand, from the view point of tunnel alignment, tunnel position is classified into four sections, that is, 1) straight section; 2) around BC (beginning of curve) section; 3) curve section; and 4) around EC (end of curve) section. Fig. 2 shows the geometric conditions at each section for each machine type. On different excavation sections, different operation rules should be considered respectively.

2.3 Calculation procedure
Fig. 3 shows the flowchart to determine articulation angle and copy cutter length on a 3D compound alignment. The calculation procedure is as follows:
1) The shield axis direction of rear body and the coordinates at P_{CSE} are calculated using the planed tunnel alignment under the assumptions 1) and 2);
2) The articulation angle is calculated using a geometric condition under the assumption 3);
3) The shield axis direction of front body and the coordinates at the crease center are calculated using a geometric condition; and
4) The copy cutter length is defined by the length from the circumference of cutter face to the most outer trace of front body and rear body under the assumption 4).

3 ANALYSIS CASE

3.1 Shield
This study assumed an articulated slurry shield with the dimensions shown in Table 2. Then,
\begin{align*}
  L_1 &= L_{M1} - L_{CSE} = 1.47 \text{m} \\
  L_2 &= L_{M2} - L_{CSE} = 1.57 \text{m} \\
  \text{Max}(L_1, L_{CSE}, L_2) &= L_{CSE}
\end{align*}
Therefore, the shield is categorized as Type2.

3.2 Tunnel alignment
This study assumed a 3-D compound alignment, which is composed of the horizontal alignment with a
4 RESULTS AND DISCUSSION

The calculated articulation angle in horizontal and vertical direction are shown in Fig. 5. The contour map of the obtained copy cutter length (CCL) distribution around the circumference of the tunnel is shown in Fig. 6. From these figures on shield operations, the following are found.

1) Area 1: Vertical curve

The articulation angle in vertical direction, $\theta_{V}$, increases from zero to 2.5 degree and decreases to zero degree quickly around Area 1. However, the one in horizontal direction, $\theta_{H}$, is approximately zero.

The copy cutter length, CCL, in the distance from -2m to 2m and 6m to 10m has positive values around the tunnel bottom (0 degree) and, the CCL in the distance from 2m to 6m has positive values around the tunnel crown (180 degree). These are because the shield is in the upward vertical circular curve. The CCL attained to maximum value (33mm) along the tunnel crown (the major normal direction of the tunnel alignment), and the CCL shows minimum value (zero) along the tunnel bottom (the opposite major normal direction of the tunnel alignment). These come from the assumption 3) in “2.1 Assumption”.

2) Area 2: Horizontal curve

The $\theta_{H}$ increases gradually along the tunnel alignment, the $\theta_{V}$ almost equals to zero, and the CCL is applied around the leftward spring line, since in this...
area the shield is in the clothoid curve and the cutter face touches the trace of the rear body on the opposite major normal direction of that curve, which creates the gap at the inner side of the curve. Therefore, the CCL distributes along the major normal direction of the curve and around the left spring line of the tunnel. Note that in this area, the major normal direction faces to the left spring line of the tunnel.

3) Area 3: 3D curve

The both of $\theta_{3H}$ and $\theta_{3V}$ decrease to negative value. The CCL is applied to the both of the rightward on horizontal direction and the downward on vertical direction, and distributes mostly around the 315 degree point (from 270 degree to 360 degree). These are because the shield is in a 3D compound curve which is composed of the rightward horizontal circular curve and the downward vertical circular curve, and the gap is created at the inner side of that curve due to the assumptions 3) and 4) in “2.1 Assumption”.

4) Area 4: Horizontal curve

The $\theta_{3H}$ is a negative constant value, the $\theta_{3V}$ is zero, and the CCL distribution is uniform along the tunnel alignment. This tendency is similar to Area 2. But since the rotation direction of the shield is opposite, the major normal direction of the curve is also reverse. The CCL is applied in the opposite side at Area 2.

5 CONCLUSIONS

The followings can be concluded through this study.
1) The articulation angle depends on shield dimension, tunnel alignment and operation rules of shield rotation.
2) The copy cutter length distributes across the major normal direction of the tunnel about a half of the skin plate area.
3) The analysis results demonstrate that the proposed method can provide articulation angle and copy cutter length and range reasonably from the view point of geometric conditions.

ACKNOWLEDGEMENTS

This work was supported by MEXT/JSPS KAKENHI Grant Number (24560563).

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