

Finite Element Simulation of Construction Processes of A Mechanized HEP & JES Tunnelling Method

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Abstract

HEP & JES tunnelling method is a new mechanized tunnelling method for soft soil ground which marries two existing tunnelling systems that is (1) "H"igh-Speed "E"lement "P"ull Method) and (2) "J"ointed "E"lement "S"tructure Method). The HEP & JES tunnelling method is applied for constructing large scale tunnels undercrossing existing railways in urban areas. During HEP & JES tunnelling operation, a rectangle tube element is driven forward by applying mechanical jack forces and excavating the soil in front of the element with boring machine. Injected elements serve as the building blocks for tunnel lining in the ground and the excavation of soil is performed after completion of tunnel lining.

In this study, the advancement and excavation processes of the HEP & JES tunnelling operation are modelled using the finite element method in order to investigate the effect of these construction processes on the ground responses. The operation of element advancement is simulated using the finite element remeshing technique at each time step of the analysis. Three dimensional FEM analyses are conducted to simulate the construction process of HEP & JES tunnelling work in Tokyo and the numerical results are compared with the field measurements.

Keywords: HEP & JES tunnelling method, finite element method, displacement

1 INTRODUCTION

The HEP & JES tunnelling method [1] is the name given to the new method for making tunnels where the wall structure is first formed by numerous segmental tunnels by excavation using a small rectangular tunnel boring machine, of which adjacent sections of the segmental tunnel are then integrated together by the JES joints, after which a soil within the internal section of the wall structure is then excavated (see Figure 1).

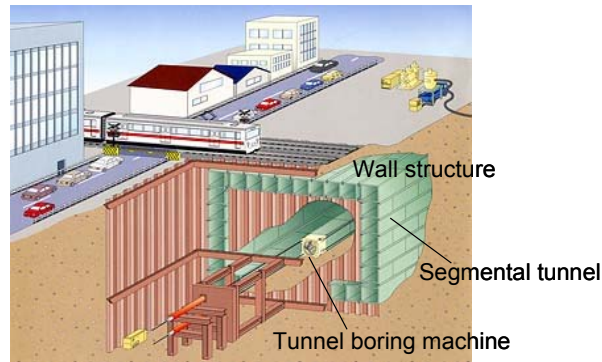


Figure 1: Overview of HEP & JES tunnelling method

As the excavation by the tunnel boring machine is of small scale and guided by the existing adjacent segmental tunnel, it is possible to carry out safe construction even where the overburden is small, and an overall safe environment can be made with regards to controlling an influence on normal traffic during construction. Therefore, as the HEP & JES tunnelling method has a variable for a large cross section with an extremely shallow overburden earth coverage, the method has been used extensively for the construction of road tunnels under the existing rail track where the road alignment can not go very deep. Since many advances such as the development of new excavation machines have been made in order to optimise the HEP & JES tunnelling method, the magnitude of soil deformation has become small. However even with recent advancements of the method, tunnelling in soft clayey ground, where the SPT-N value is close to zero, is still a major technical challenge to engineers.

In this study, the advancement and excavation processes of the segmental tunnel are modelled using the finite element method in order to investigate the effect of these construction processes on the ground response. The proposed modelling techniques are applied to simulate HEP & JES tunnelling work in Tokyo and the numerical results are compared with the field measurements.

2 FINITE ELEMENT MODELLING OF EXCAVATION AND ADVANCEMENT OF THE SEGMENTAL TUNNEL OF THE HEP & JES TUNNELLING METHOD

In this study, the excavation process is modelled by introducing excavating finite elements in front of the tunnel boring machine [2]. The advancement of the segmental tunnel is modelled by (i) remeshing the finite elements at each time step, (ii) introducing the excavating finite elements of a fixed size in front of the tunnel boring machine, and (iii) applying external forces for the advancement of the segmental tunnel.

In HEP & JES tunnelling method, the segmental tunnel is elongated successively by adding and seaming a prefabricated element at the end of the constructing segmental tunnel. In this analysis, however, once the tunnel boring machine passed, the nodal displacements adjacent to the tunnel lining were fixed in position.

Sequential illustrations of the finite element modelling of the excavation at the cutting face of the tunnel boring machine and the advancement of the machine and the segmental tunnel are shown in Figure 2.

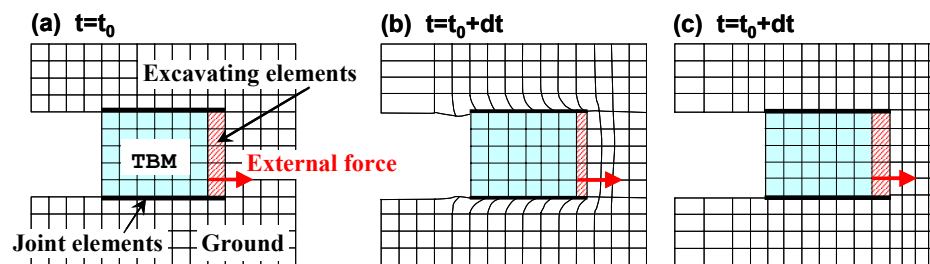


Figure 2: Advance of the TBM simulated by using the excavating elements

Figure 2(a) shows the status of the tunnel boring machine and segmental tunnel at reference time t_0 . In order to model the external forces applied to the tunnel boring machine, forces are applied at the nodes of the tunnel boring machine. During the time interval of t_0 to t_0+dt , the excavating elements and the soil elements adjacent to the tunnel boring machine elements will deform by the external force (Figure 2(b)).

The tunnel boring machine will act as rigid bodies since a large value of stiffness is used for the elements representing the tunnel boring machine.

After obtaining a solution for $t = t_0+dt$, the finite elements are remeshed as shown in Figure 2(c). The new mesh will have the same mesh geometry relative to the tunnel boring machine as $t = t_0$, but the location of the shield machine has shifted. Again, the

excavating elements will be placed in front of the cutting face before applying external forces given for the next time step.

By doing so, the construction processes of the segmental tunnel of HEP & JES tunnelling method and the associated stress-strain changes of the ground are numerically simulated in a continuous manner.

3 FINITE ELEMENT SIMULATION OF A HEP & JES TUNNELLING

A soil-water coupled three dimensional elastic finite element analysis was conducted to simulate the construction process of the wall structure of a HEP & JES tunnelling in Tokyo. The sixty rectangular segmental tunnels of 0.85 m width, 0.85 m height and 30.0 m long were constructed in order to build the wall structure. These tunnels were integrated finally to the wall structure in approximately 23.10 m width and of 8.14 m height with an earth coverage of only 1.20 m underneath major rail tracks. The site stratigraphy determined from borehole logs is shown on the cross section in Figure 3.

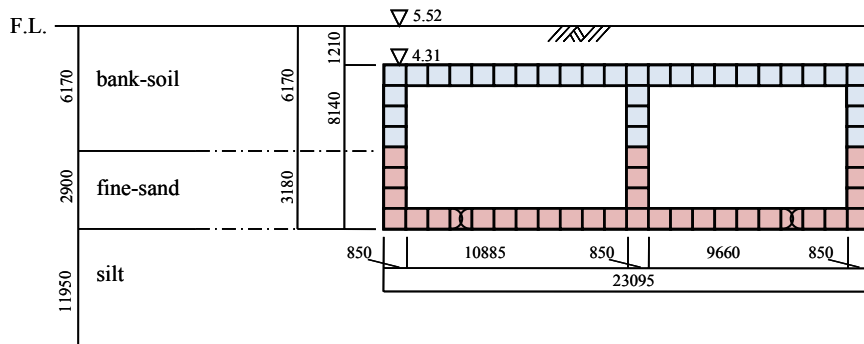


Figure 3: Advance of the TBM simulated by using the excavating elements

Summary descriptions of the soil divisions and input parameters based on the examination of site samples were given below:

- (1) bank-soil : $E=5600 \text{ kN/m}^2$, $\nu=0.333$, $\rho=1.735 \text{ g/cm}^3$
- (2) fine sand : $E=5600 \text{ kN/m}^2$, $\nu=0.333$, $\rho=1.786 \text{ g/cm}^3$
- (3) silt : $E=1000 \text{ kN/m}^2$, $\nu=0.444$, $\rho=1.531 \text{ g/cm}^3$
- (4) TBM and wall structure : $E=4.7 \times 10^7 \text{ kN/cm}^3$, $\nu=0.290$, $\rho=1.786 \text{ g/cm}^3$
- (5) Excavating elements : $E=300 \text{ kN/cm}^3$, $\nu=0.100$, $\rho=1.786 \text{ g/cm}^3$

where E is Young's modulus, ν is Poisson's ratio and ρ is density of soil. For the excavating elements, a Young's modulus of 700 kN/m^2 , Poisson's ratio of 0.1 and the thickness of 1 m were selected.

Figure 4 shows the order of the segmental tunnel construction. The segmental tunnels (B, C, D, E) at the top part of the wall structure were first constructed, and then the segmental tunnels (F, G, H) at the vertical wall were constructed, after which the segmental tunnels (L, M, N, O) at the invert wall were constructed.

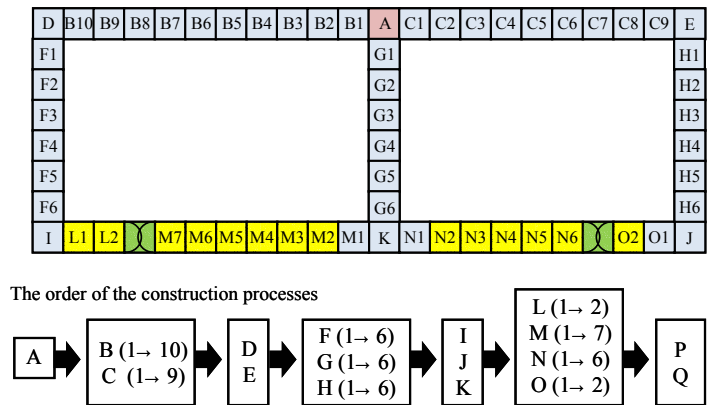


Figure 4: The order of the construction processes

During constructing the segmental tunnel (L, M, N, O) at the invert part of the wall structure, the contractor measured vertical displacements of the existing top part of the wall structure at (already integrated) B10, B5, A, C5 and C9.

Figure 5 shows the computed transverse vertical displacement of the end of the top part of the wall structure during the segmental tunnels N2 and L1 advancement. The measured data at the monitoring points B10, B5, A, C5 and C9 are also plotted in the figure.

The calculated result of vertical displacement was larger than the measured data. Both the calculated and measured result showed that there is an ununiform settlement toward the segmental tunnel L1.

4 CONCLUSIONS

In this paper, the advancement and excavation processes of the new HEP & JES tunnelling operations were modelled using the finite element method in order to investigate the effect of these construction processes on the ground response. A excavating finite element introduced in front of the cutting face of the tunnel boring machine, and the operation of segmental tunnel advancement and of soil excavation was simulated using the finite element remeshing technique at each time step of the

analysis. The proposed modelling techniques were applied to simulate a HEP & JES tunnelling work in soft cohesive soil in Tokyo and the results were compared with the field measurements. Although the calculated result was larger than the measured data, both the calculated and measured vertical displacements show that there is an ununiform settlement toward the segmental tunnel L1.

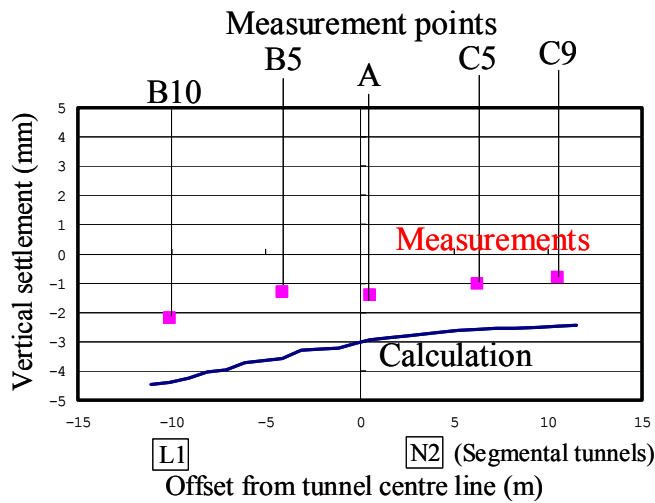


Figure 5: Settlement troughs for construction of the segmental tunnel N2 and L1

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