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Numerical Analysis on Mutual Influences in Urban Subway Double-Hole Parallel Tunneling

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Abstract: mutual influence of the double-hole tunnel evacuation of urban subways is one of key issues involving the subway construction safety. The asynchronous one-direction evacuation, synchronous one-direction evacuation and opposite evacuation methods are frequently used in double-hole tunnel evacuation. This paper establishes three-dimensional numerical model by using the finite element analysis software MIDAS/GTS v2.01 and mainly studies the mutual influences of tunnels in the asynchronous one-direction evacuation and synchronous one-direction evacuation. The following conclusions are concluded based on computing. The preliminary conclusion is that the influential distance between the evacuation section of two tunnels is 3D (D is the tunnel diameter) in the parallel tunnel asynchronous evacuation, namely when the lagging distance is more than 3D, the lagging evacuation tunnel will not affect the advance evacuation tunnel section. The asynchronous evacuation of the vertical distribution tunnel is divided into the up tunnel first evacuation and down tunnel first evacuation. For up tunnel first evacuation, the influence range of the lagging distance is 5D. For down tunnel first evacuation, the influence range of the lagging distance is 1D. For up tunnel first evacuation on the slope, the influence range of the lagging distance is 5D. On the whole, the influence of two tunnels in up tunnel first evacuation is bigger than it in down tunnel first evacuation. The numerical analysis results will have important theoretical meaning and application value for building technology of the parallel double-hole tunnel.

Keywords: Mutual influence, numerical analysis, subway, tunnel.

1. INTRODUCTION

With sustainable and quick growth of the economy and speed-up of urbanization in China, the population is increasingly expanding in large-scale and middle-scale cities in China. The aboveground traffic is prone to saturation in cities. Subway brings better social and economy benefits due to environmental protection and high efficiency and is gradually becoming the main traffic mode in modern cities. The shield method is the frequent method for subway construction, but it will avoidably lead to different disturbances to the ground, will generate the increasing load on the surrounding earth, change the stress state of the earth, and lead to the stratum shift and surface sedimentation. When the stratum distortion is over certain range, it will endanger the adjacent buildings and structures, even lead to disaster [1-2] and a series of environment earthwork problems [3]. In recent years, the density and depth of the underground space development is continuously increasing. Tunneling based on shield method is restricted by the city construction plan and adjacent existing buildings and two or more parallel tunnels will be constructed on one section. E.g. multi-channel work at the Waterloo subway station, London, England [4], construction of four near shield tunnels at a zone of Misasagi East subway, Kyoto, Japan, in which the minimal gap is only 0.6m [5], Yuexiu garden subway station and Jiangnan New Village subway station in Guangzhou subway phase II work, in which three-hole tunnel scheme is used and the minimal net distance of three-hole tunnel is only 2.7m [6], No. 11 bidding section of Beijing subway No. 10 line, in which the minimal gap between left and right tunnel is only 1.7m and the parallel net distance of 80.1 m line is less than 2m [7]. One tunnel is constructed beside the existing tunnel due to overlapping of influences. The operating tunnel has big influences on evacuation of new tunnels. On the contrary, the new tunnel evacuation has complicated influences on the existing tunnels or underground chambers. The scholars at home and abroad conducts a series of research on this problem [8-10]. The mutual influences of double-hole parallel tunneling is very complicated and influence factors are plentiful, so studying the dynamical behaviors of the parallel tunneling, perform numerical analysis on the system and grasping mutual influences of different factors on the tunnel evacuation and different effects of surface sedimentation have important theoretical meaning and application value for building technology of the parallel double-hole tunnel. This paper establishes simple three-dimensional numerical model by using the finite element analysis software, mainly study mutual influences between tunnels in asynchronous one-direction evacuation and synchronous one-direction evacuation. For asynchronous one-direction evacuation, the influences on the earth around the tunnel evacuation surface will be analyzed when the distance between the evacuation sections of two tunnels is difference in shield forwarding.

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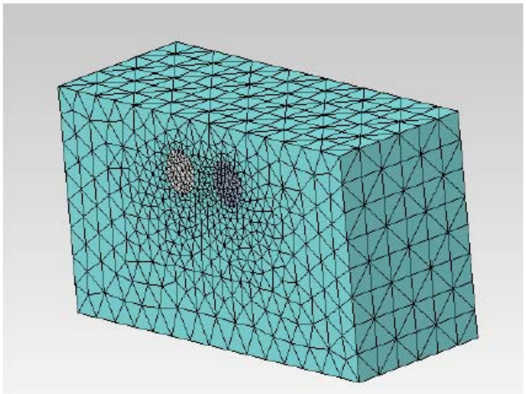
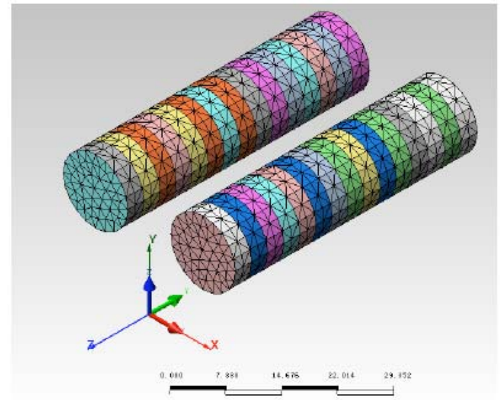


(**a**) Single soil layer double-hole tunnel model



(**b**) Construction model diagram of double-hole tunnel section

Fig. (1). Three-dimensional finite element model.

Table 1. Dynamics parameters of soil layer.

Soil layer	Gravity /kNm^{-3}	Distortion modulus /MPa	Poisson ratio	Internal friction angle /°	Cohesive strength /kPa
Typical soil layer	19.40	4.3	0.3	16.1	49.2
Concrete C40	25.00	1000	0.15	/	/

2. PROPERTY INFLUENCE ANALYSIS OF ASYNCHRONOUS EVACUATION OF DOUBLE-HOLE PARALLEL TUNNEL

2.1. Computing Model and Parameters

The basic computing model is shown as the Fig. (**1**).

X axis and Y axis respectively indicate the width direction and depth direction. Z axis indicates the tunnel axis direction. The width is 120m in X direction of the model, the depth is 60m in Y direction and the length is 45m in Z direction. The diameter D of two tunnels is 6m in the model of this chapter. Two tunnels are located on one horizontal line and are parallel to each other. The gap is 6m (namely 1D) and the burying depth is 9m (namely 1.5D). Mohr-Coulomb model is used for analysis. To simplify computing, only single soil layer is used for analysis. The soil layer parameters are shown as the Table **1**.

The boundary conditions of the model are described as follows: the bottom of the soil layer is a fixed boundary, which will restrict horizontal shift and vertical shift. The left and right horizontal constraints of the soil layer will restrict the horizontal shift. The up surface of the soil layer is the ground surface and is set as the free boundary. 15 sections are set in modeling to simulate 15 dynamic evacuation. Each evacuation step is 3m.

Generally the asynchronous one-directione vacuation, synchronous one-directione vacuation and opposite evacuation are used in double-hole tunnel evacuation. This paper mainly studies mutual influences of tunnels in the asynchronous one-direction evacuation and synchronous one-direction evacuation. For asynchronous one-directione vacuation, the influence on the soil body around the tunnel evacuation surface is analyzed when the gap between the evacuation section of two tunnels in the shield advance. For overview of specific analysis, refer to the Fig. (**2**). Assume that the left tunnel is first evacuated and the right tunnel is then evacuated. ab, ac, ad and ae indicate distance between the right tunnel evacuation section and left tunnel evacuation section in the figure, namely lagging distance (expressed as L), which respectively indicate 0D, 1D, 2D, 3D and 5D (D indicates the diameter of the tunnel).

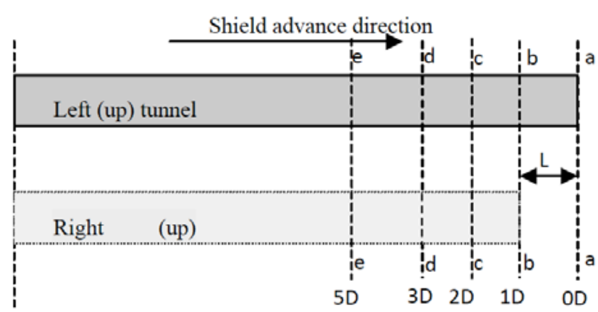


Fig. (2). Overview on asynchronous evacuation research.

2.2. Soil Layer Shift Around Tunnel Section

To survey the soil layer shift around the tunnel, the polar coordinate is used to divide the tunnel perimeter into 20 parts in X direction and one point is taken every 18° on the tunnel perimeter, shown as the Fig. (**3**). The Fig. (**4 and 5**) indicate the comparison curve of the horizontal shift and vertical shift of the points around the left and right tunnel when the lagging distance is 0D (namely 0m) and the tunnel is evacuated till 45m. The Fig. (**6 and 7**) indicate the comparison curve of the horizontal shift and vertical shift of the points around the left and right tunnel when the lagging distance is 3D (namely 18m) and the left tunnel is evacuated till 45m.

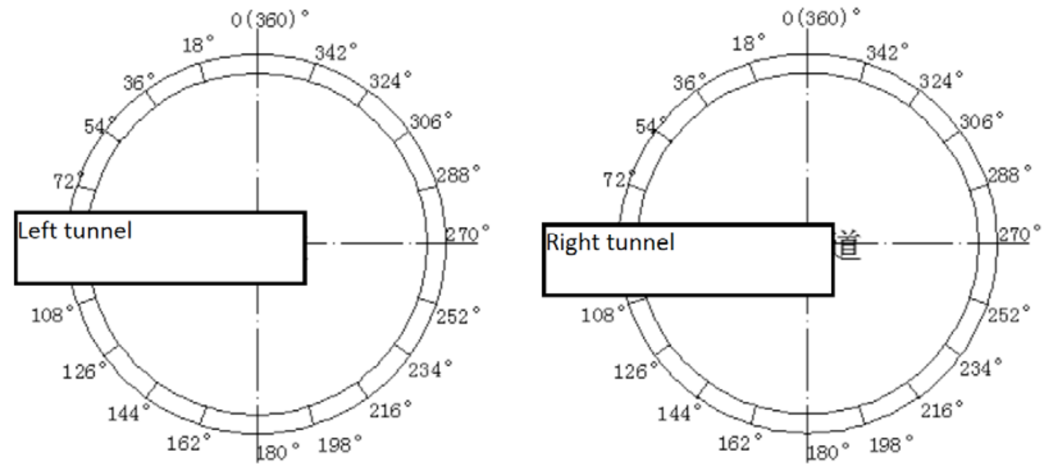


Fig. (3). Position around tunnel.

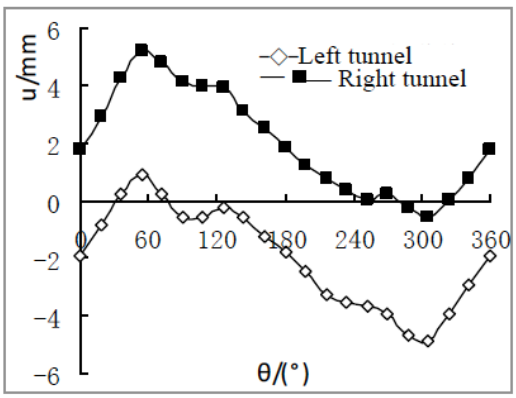


Fig. (4). Horizontal shift of points around tunnel (L=0D).

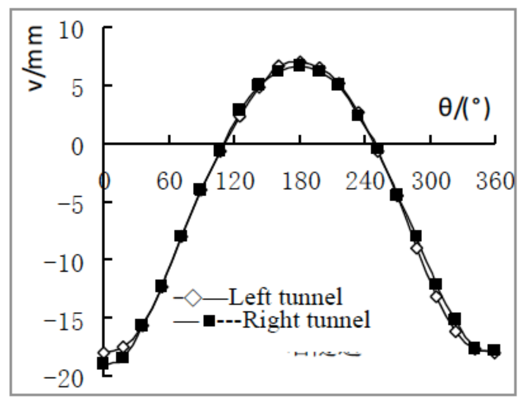


Fig. (5). Vertical shift of points around the tunnel (L=0D).

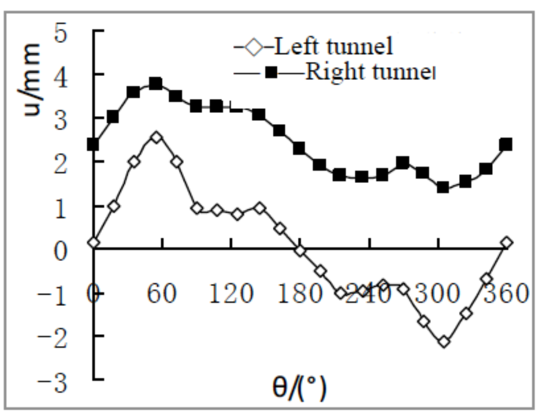


Fig. (6). Horizontal shift of points around the tunnel (L=3D).

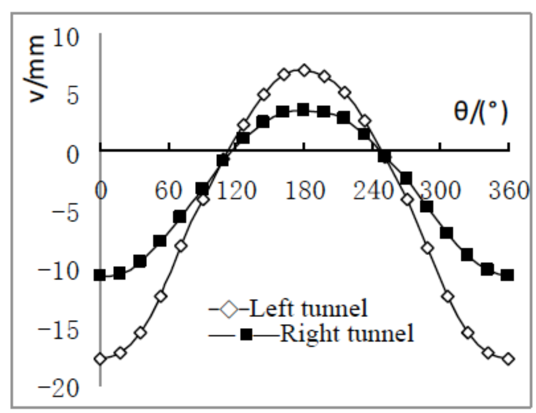


Fig. (7). Vertical shift of points around the tunnel (L=3D).

On the whole, when the gap between two evacuation sections (lagging distance L) is smaller in asynchronous evacuation of the double-hole parallel tunnel, the mutual influences between tunnels are bigger. After the lagging distance increases from 0D to 1D, the influences on the right tunnel is bigger than it on the left tunnel and the influence on the vertical shift around the left tunnel evacuation section is not big and the influence on the horizontal shift around the section is bigger, but the influences on the vertical shift and horizontal shift of the right tunnel evacuation section is big. When the lagging distance is over 3D, the influences of the lagged evacuation tunnel on the advance evacuation tunnel can be ignored, namely evacuation of advance evacuation tunnel and single-hole tunnel evacuation are nearly same, so the right tunnel lagging evacuation can facilitate distortion of the soil around two tunnels. The lagging distance has little influences on the vertical sedimentation around the left tunnel and the influence on the vertical sedimentation around the right tunnel and horizontal shift around the left and right tunnel is big.

2.3. Surface Sedimentation of Tunnel Section

The Fig. (**8**) displays the surface sedimentation curve of the evacuation section when the left tunnel evacuates to 45m in different lagging distance.

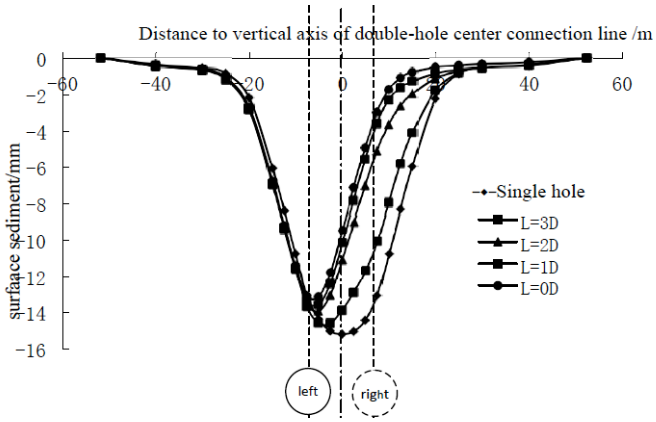


Fig. (8). Surface sedimentation curve of left tunnel evacuation section.

The figure indicates that when two tunnels are evacuated synchronously (namely L=0D), the maximum of the surface sedimentation curve will occur on the vertical axis of the double-hole center connection line. when two tunnels are evacuated asynchronously (namely L>0D), with growth of evacuation surface distance, the maximum of the surface sedimentation curve will approach to the left tunnel center line and the surface sedimentation maximum will become smaller and smaller till the left tunnel is individually evacuated. The maximum of the surface sedimentation curve occurs at the center line of the left tunnel. Regardless of gap between two sections, the surface sedimentation on the left of the left tunnel nearly does not change and the surface sedimentation of the soil between two tunnels changes much. It indicates that the surface sedimentation mainly displays on the soil body between two tunnel center lines in asynchronous evacuation. Observation finds that the surface sedimentation curve and the surface sedimentation curve of the left tunnel individual evacuation are similar when the gap of evacuation surfaces of two tunnels is 3D. it indicates that the mutual influences of the lagging evacuation tunnel (right tunnel) section and advance evacuation tunnel (left tunnel) section becomes smaller. By comparing the curves in the figure, it indicates that the evacuation surface of two tunnels approaches to zero when the gap between the evacuation surface is more than 3D.

3. PROPERTY INFLUENCE ANALYSIS OF ASYNCHRONOUS EVACUATION OF VERTICAL OVERLAPPING DOUBLE-HOLE TUNNEL

The tunnel is distributed differently. Besides the parallel tunnels, vertically overlapping tunnels are also frequent. This section analyzes the asynchronous evacuation properties of the vertically overlapping double-hole tunnel. The burying depth of up line tunnel is 9m and the gap between down line and up line is 6m in the model, namely the burying depth of down line is 21m. Other parameters are same as them in the above section. The vertically overlapping double-hole asynchronous evacuation is divided into the up line advance evacuation and down line lagging evacuation and up line lagging evacuation and down line advance evacuation. This section will compute and analyze tunnel evacuation in two cases.

3.1. Property Influence Analysis in Up Tunnel First Evacuation

3.1.1. Shift of Soil Layer Around Tunnel Section

The Fig. (**9** and **10**) indicate comparison of the horizontal shift curve and vertical shift curve of points around the up tunnel evacuation section with them for up line separate evacuation when the up tunnel evacuates till 45m. The Fig. (**11** and **12**) indicate comparison of the horizontal shift curve and vertical shift curve of points around the up tunnel evacuation section with them for up line separate evacuation when the up tunnel is first evacuated, the lagging distance is 3D, and the up tunnel is evacuated to 45m.

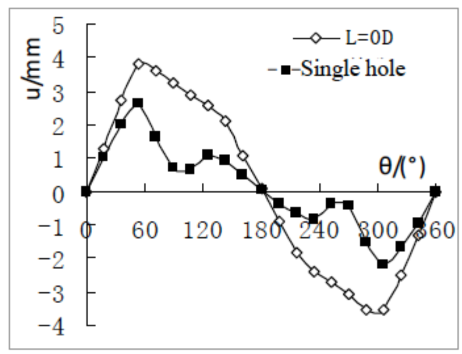


Fig. (9). Horizontal shift of points around up tunnel.

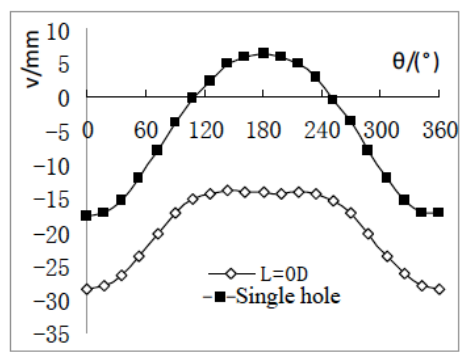


Fig. (10). Vertical shift of points around up tunnel.

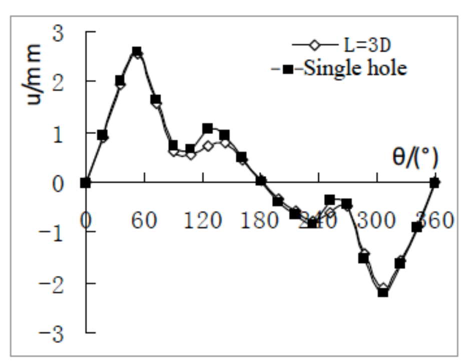


Fig. (11). Horizontal shift of points around up tunnel.

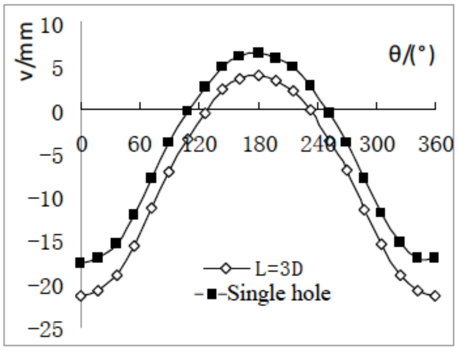


Fig. (12). Vertical shift of points around up tunnel.

Comparison of above several cases indicate that the lagging tunnel evacuation has little influences on the horizontal shift around the advance tunnel evacuation section when the down tunnel lagging evacuation is over 3D. When the down tunnel lagging evacuation is over 5D, the lagging tunnel evacuation has little influence on vertical shift of the advance tunnel evacuation section.

3.1.2. Surface Sedimentation of Tunnel Section

The Fig. (**13**) shows the surface sedimentation curve of the evacuation section in different lagging distances when the up line tunnel is evacuated to 45m.

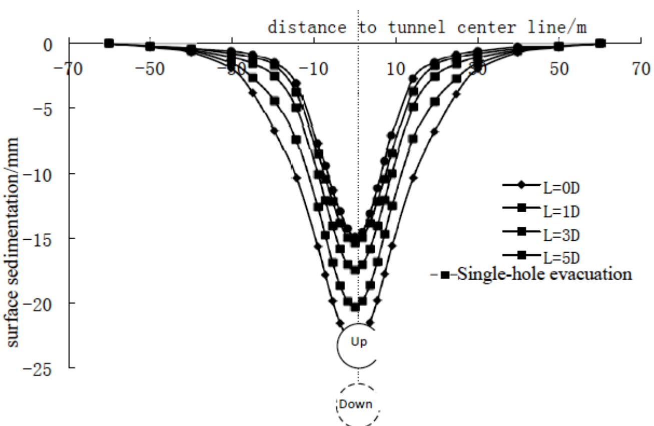


Fig. (13). Surface sedimentation curve of up line tunnel evacuation section.

The figure indicates that the maximum of the surface sedimentation curve occurs at the tunnel center line. With growth of the evacuation surface distance, the maximum of the surface sedimentation curve becomes smaller and smaller. when the gap of the up and down tunnel evacuation section is over 5D (30m), the surface sedimentation curve is similar to the surface sedimentation of single-hole tunnel evacuation, namely the up tunnel has little influences on the up tunnel evacuation section.

3.2. Property Influence Analysis of Down Line First Evacuation

3.2.1. Soil Layer Shift Around Tunnel Section

The Fig. (**14** and **15**) indicates comparison of horizontal shift curve and vertical shift curve of the points around the tunnel with them for down tunnel separate evacuation when the down tunnel is first evacuated and the lagging distance is 0D. The Fig. (**16** and **17**) indicates comparison of horizontal shift curve and vertical shift curve of the points around the tunnel with them for down tunnel separate evacuation when the down tunnel is penetrated.

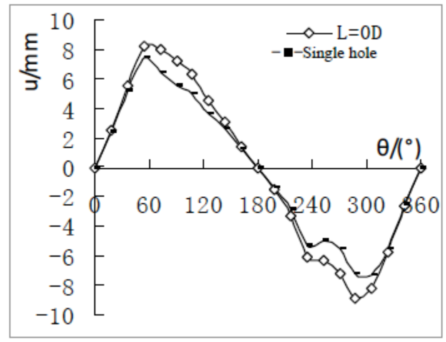


Fig. (14). Horizontal shift of points around down tunnel.

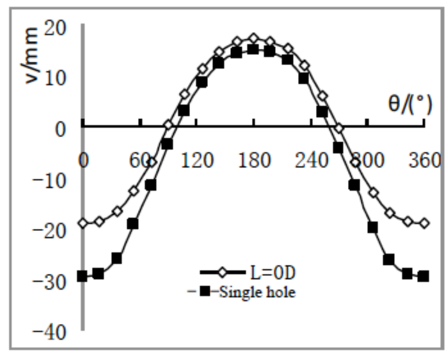


Fig. (15). Vertical shift of points around down tunnel.

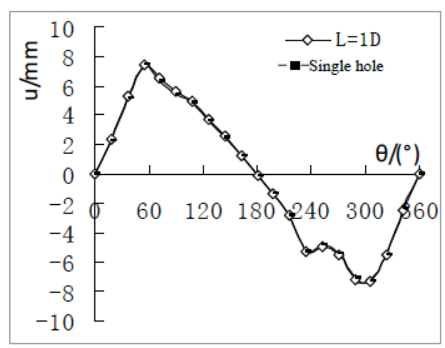


Fig. (16). Horizontal shift of points around down tunnel.

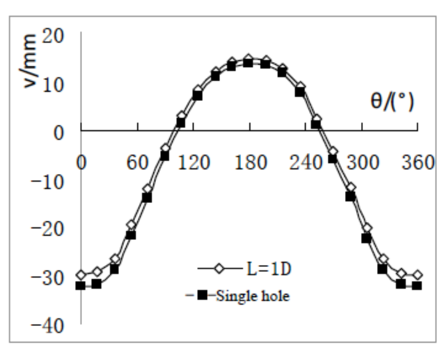


Fig. (17). Vertical shift of points around down tunnel.

The computing results indicate that the horizontal shift curve and vertical shift curve around down line evacuation section is nearly same as the curve for down line separate evacuation when the down tunnel is first evacuated and the gap L of the vertically overlapping distributed two-tunnel evacuation surface is 1D(6m), it indicates that up line tunnel has no little influence on shift of the soil layer around the down line tunnel evacuationsurface.

3.2.2. Surface Sedimentation of Tunnel Section

The Fig. (**18**) indicates the surface sedimentation curve of the evacuation section when the down tunnel is evacuated to 60m in different lagging distance.

The Fig. (**18**) can clearly indicate that the maximum of the surface sedimentation curve occurs at the tunnel center line. With growth of the gap between two tunnel evacuation surface, the maximum of the surface sedimentation curve becomes smaller and smaller. when L>1D, the surface sedimentation curve is nearly same as the surface sedimentation for single-hole tunnel evacuation, namely when the gap of the up and down tunnel evacuation section is over 1D (6m), the up and down tunnel has little influence on the soil body around the down tunnel evacuation section.

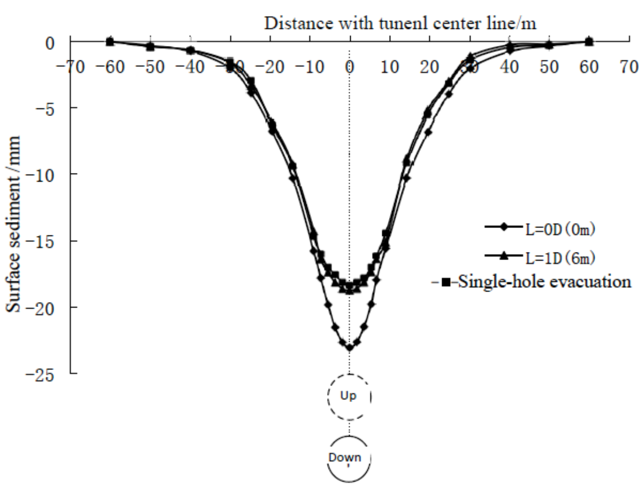


Fig. (18). Surface sedimentation curve of down line tunnel evacuation section.

4. PROPERTY INFLUENCE ANALYSIS OF ASYNCHRONOUS EVACUATION OF TILTED OVERLAPPING DISTRIBUTION TUNNEL

For distribution of the double-hole parallel tunnel, besides the parallel distribution and vertical distribution, the tilted overlapping is available. This section will analyze influences on the asynchronous evacuation property of the double-hole tunnel (shown as the Fig. **19**) with tilting angle 45° (angle between double-hole tunnel center connection line and horizontal line) via the numerical computing.

Based on the analysis in the above section, the influence of the up tunnel first evacuation on the double-pole tunnel is bigger than it on the down tunnel first evacuation under verticaloverlapping distribution and the tilted distribution is the “middle” form of the parallel distribution and vertical distribution, so this section computes and analyzes the tilted distributed tunnel of the up tunnel first evacuation.

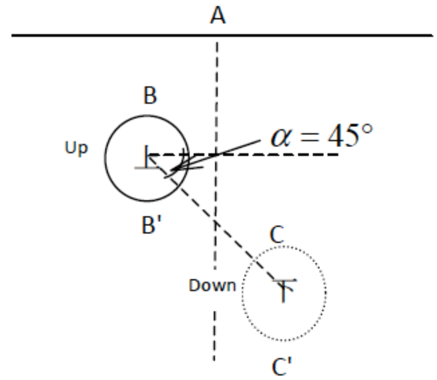


Fig. (19). Position of tunnel distribution and monitoring points.

4.1. Soil Layer Shift Around Tunnel Section

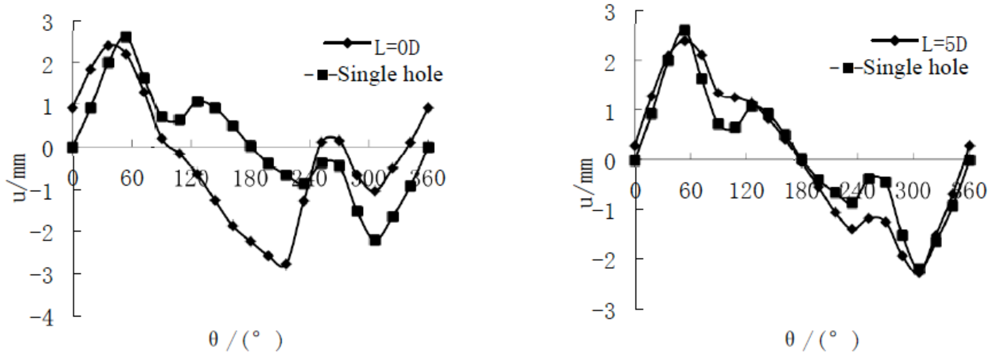
The above analysis indicates that the influence scopes of lagging distances of double-hole tunnel asynchronous evacuation is different in different distributions. This section compares the evacuation information of the tilted overlapping double-hole tunnel in different lagging distances with it of single-hole tunnel evacuation to know the change of the shift of points around the up tunnel with growth of the lagging distance in tilted overlapping distribution. The Fig. (**20**) indicates the horizontal shift curve of points around the up tunnel with growth of lagging distance when the up tunnel is evacuated to 45m.

The change law of the horizontal shift curve and vertical shift curve around the up tunnel indicates that the influence range of the lagging distance is 4D in tilted distribution ($\alpha = 45°$), namely when the distance of down tunnel lagging evacuation is over 4D, the evacuation of the up tunnel section is seldom affected by the down tunnel.

4.2. Surface Sedimentation of Tunnel Section

The Fig. (**21**) shows the surface sedimentation curve of evacuation section at different lagging distances when the left tunnel is evacuated to 45m. The figure clearly indicates that the surface sedimentation curve maximum does not occur at the vertical axis of double-hole center line and occurs on the left side of the vertical axis of the double-pole center line when two tunnels are synchronous evacuated (namely L=0D), namely close to left tunnel.

When two tunnels are evacuated asynchronous (namely L>0D), with growth of the evacuation surface distance, the maximum of the surface sedimentation curve will approach the center line of the up tunnel and the maximum of the surface sedimentation will become smaller. The surface sedimentation curve is very similar to it of the up tunnel separate evacuation when the lagging distance meets the condition L>4D, namely the lagging evacuation down tunnel seldom affects up tunnel evacuation surface within this range. The surface sedimentation diagram clearly indicates that the left surface sedimentation of the up tunnel has little change regardless of gap of two sections, but the surface sedimentation of the soil between two tunnels changes much, it indicates the influences of surface sedimentation mainly occur on the soil between two tunnel center lines in asynchronous evacuation.



(a) (b)

Fig. (20). Horizontal shift of points around up tunnel with growth of lagging distance.

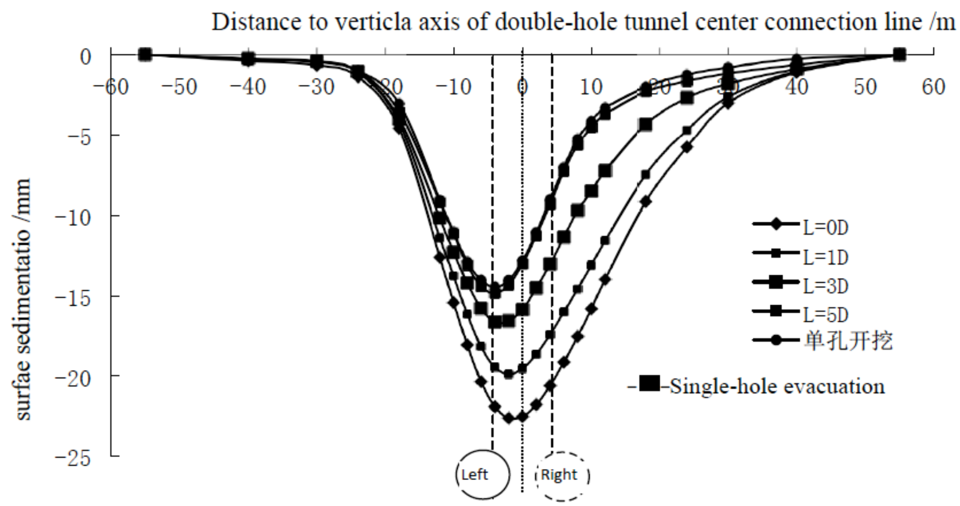


Fig. (21). Section surface sedimentation when up tunnel is evacuated to 60m.

CONCLUSION

This paper establishes a simple three-dimensional numerical model by using finite analysis software MIDAS/GTS v2.01 and mainly studies mutual influences of tunnels in asynchronous one-direction evacuation and synchronous one-direction evacuation. The following conclusions can be concluded via computing:

(1) For parallel tunnel asynchronous evacuation, the influence distance of two tunnel evacuation sections is 3D, namely when the lagging distance is over 3D, the lagging evacuation tunnel has no influences on the advance evacuation tunnel section. Thevertical distribution tunnel asynchronous evacuation is divided into the up tunnel first evacuation and down tunnel first evacuation. For up tunnel first evacuation, the influence range of the lagging distance is 5D. For down tunnel first evacuation, the influence range of lagging distance is 1D. For the up tunnel first evacuation in tilted distribution, the influence range of the lagging distance is 5D. On the whole, the influence of two tunnels in up tunnel first evacuation is bigger than it down tunnel first evacuation.

(2) For synchronous evacuation of two parallel tunnels (namely L=0D), the surface sedimentation curve maximum occurs on the vertical axis of the double-hole center line. forasynchronous evacuation of two tunnels (namely L>0D), with growth of evacuation surface distance, the maximum of the surface sedimentation curve will approach to the left tunnel center line and the surface sedimentation maximum will become smaller. When the left tunnel is separately evacuated, the maximum of surface sedimentation curve occurs at the left tunnel center line. for asynchronous evacuation, the influence of the surface sedimentation mainly occurs on the soil between two tunnel center lines. After double-hole parallel tunnels are evacuated, the vertical shift of the tunnel vault will grow. The vertical shift of the arch bottom will also increase, but the increment is less. it is caused by vertical compression and reduction of the middle rock pole.

(3) For vertical overlapping double-hole tunnel, regardless of up tunnel or down tunnel first evacuation, the maximum of surface sedimentation curve occurs at the tunnel center line. With growth of the evacuation surface distance, the maximum of the surface sedimentation curve will become smaller. Double-hole vertical tunnel evacuation is different from single-hole tunnel evacuation. The arch bottom of the up tunnel will generate certain sedimentation because the arch bottom of the up tunnel is affected much by down tunnel evacuation.

(4) The tilted distribution is the “intermediate” form of the parallel distribution and vertical distribution. For two tunnel synchronous evacuation (namely L=0D), the maximum of the surface sedimentation curve does not occur the vertical axis of the double0hole center line and occurs on the left of the vertical axis of the double-hole center connection line, namely close to the left tunnel. For asynchronous evacuation, with growth of the evacuation surface distance, the maximum of the surface sedimentation curve will approach to the center line of the up tunnel and the surface sedimentation maximum will become smaller. When the lagging distance meets the condition L>4D, the surface sedimentation curve is nearly same as the up tunnel separate evacuation. The surface sedimentation mainly affects the soil between two tunnel center lines. The swelling of the arch bottom of the up tunnel is smaller than it of single-hole tunnel due to influence of down tunnel. Thehaunch close to the down tunnel will deviate to the down tunnel. When two tunnels are synchronously advanced, the deviation at the haunch in the down tunnel direction will reach the maximum. With growth of the lagging distance, the deviation will gradually reduce in the down tunnel direction. When the lagging distance reaches certain value (L>4D), the section convergence curve of the up tunnel is same as it of single-hole evacuation.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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