The Open Civil Engineering Journal, 2015, *9*, 44-52

Numerical Analysis on Influence of Subway Double-Hole Parallel Tunnel Deployment on Surrounding Soil Distortion

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Abstract: construction of near double-hole parallel tunnels frequently occurs in city subway evacuation. Studying the dynamical behaviors of the parallel tunnel construction, performing systematic numerical analysis and grasping mutual influences of different factors on the tunnel evacuation and different effects of surface sedimentation has important theoretical meaning and application value for the building technology of the parallel double-hole tunnel. This paper establishes a three-dimensional numeral model, analyzes influences of three main influence factors (tunnel distribution form, tunnel burying depth and tunnel gap) on the surrounding soil and surface sedimentation in double-hole tunnel synchronous evacuation. The conclusions indicate that the vertical distribution has the biggest influences on tunneling in horizontal distribution, vertical distribution and tilted distribution of two tunnels, followed by tilted distribution. The horizontal distribution has the minimal influence. With growth of the tunnel gap, the mutual influence between two tunnels will become smaller. With growth of the tunnel burying depth, the influences on tunneling will become bigger.

Keywords: Double-hole parallel, numerical analysis, soil distortion, subway, tunnel.

1. INTRODUCTION

Funded by High-level talent Technology Project of Xiamen Academy of Technology, Number: YKJ14011R.

With quick growth of economy, the pressure on the city ground traffic is becoming bigger and bigger, so the subway tunnels are constructed to alleviate this pressure in many cities. Generally these subway tunnels are constructed *via* the double-hole tunnel method [1, 2]. Generally the tunnels are distributed by smaller gap and smaller burying depth due to geology and environmental factors. The shield construction will disturb the stratum and lead to surface sedimentation, tilting, cracking or collapse of surface buildings, and damage to underground pipeline. The shield construction affects soil distortion due to many factors such as tunnel diameter, burying depth, gap of double-hole tunnel and soil structure model, shield front support pressure and additional pressure, friction between shield shell and soil (internal wall friction), over evacuation, shield tail gap and synchronous slurry injection, soil concretion, secondary concretion and long-term sedimentation caused by flow change and vertical structural distortion of tunnel, which will lead to the soil distortion and surface sedimentation around the tunnel, so the scholars at home and abroad have conducted a series of research on the influence factors of the soil distortion [3-7]. mutual influence of double-hole parallel tunneling is very complicated and includes many factors, so Studying the dynamical behaviors of the parallel tunnel construction, performing systematic numerical analysis and grasping mutual influences of different factors on the tunnel evacuation and different effects of surface sedimentation has important theoretical meaning and application value for the building technology of the parallel double-hole tunnel. This paper establishes a three-dimensional numeral model, analyzes influences of three main influence factors (tunnel distribution form, tunnel burying depth and tunnel gap) on the surrounding soil and surface sedimentation in double-hole tunnel synchronous evacuation.

2. INFLUENCE OF DIFFERENT TUNNEL DISTRIBUTIONS

The existing researches indicate that the important influence factors of the double-hole tunnel evacuation stress and distortion include gap and burying depth of the double-hole tunnel [8, 9]. This paper will compute the influences of different distribution forms on the synchronous evacuating double-hole tunnel under specific gap and burying depth. The specific construction cases are shown as the Fig. (**1**). The case 1 indicates horizontal two tunnels distribution. The case 2 indicates tilted two tunnels distribution and the case 3 indicates vertical two tunnel distribution. H=14m and B=8m in three cases.

The size, boundary condition and evacuation conditions of the computing model are same as them in the previous chapter. The three-dimensional model is shown as the Fig. (**2**).

The Fig. (**3**) shows the surface sedimentation curve of synchronous evacuation tunnels in three different work conditions.

The Fig. (**3**) indicates that the surface sedimentation maximums caused by different distribution modes are

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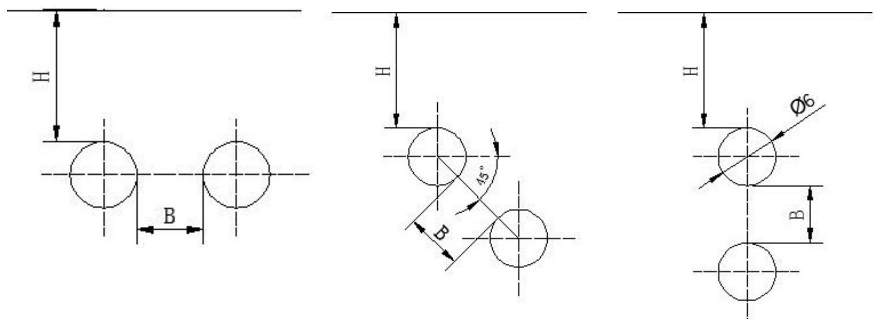
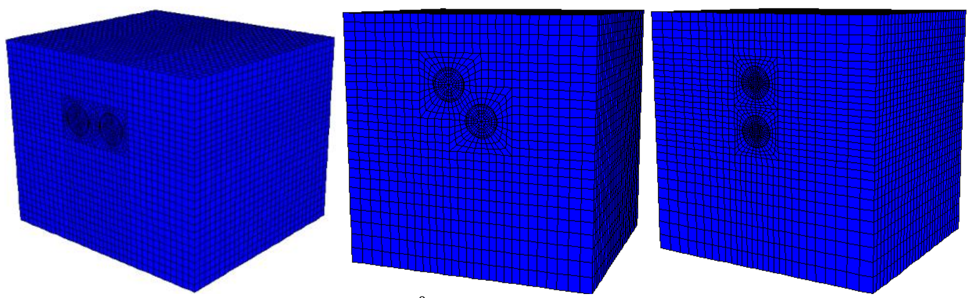


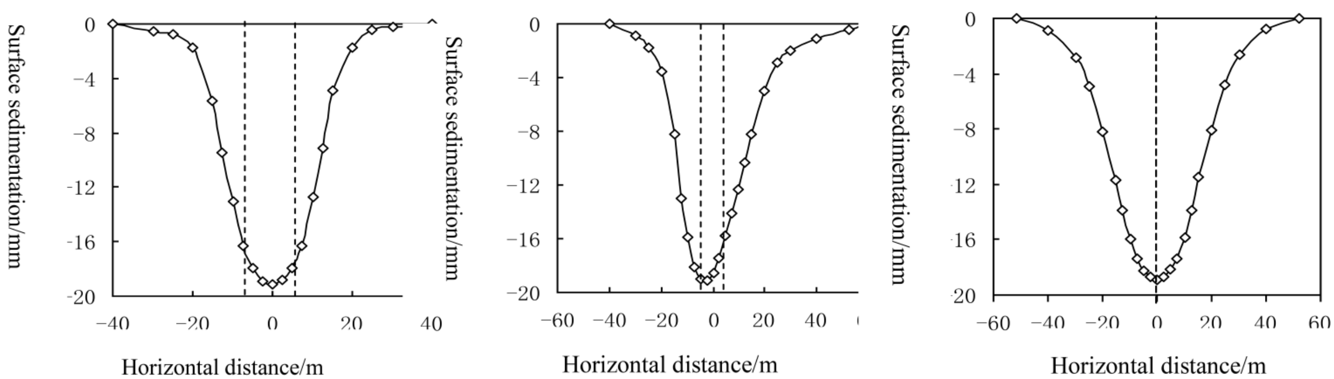
(a) Horizontal distribution (b) Tilted distribution (c) Vertical distribution

Fig. (1). Different distribution of double-hole tunneling.



(a) Horizontal and parallel (b) 45^0 tilted overlapping (c) Vertical overlapping

Fig. (2). Schematic diagram of three-dimensional model.



(a) Horizontal and parallel distribution (b)Vertical overlapping distribution (c)Tilted overlapping distribution

Remark: The broken line indicates the up and down tunnel center line in the figure.

Fig. (3). Surface sedimentation curve of synchronous evacuation tunnel in three work conditions.

similar in double-hole tunnel synchronous evacuation, but it will affect the position of the surface sedimentation maximum to certain extent. The position of the surface sedimentation maximum caused by construction in three different conduction conditions depends on the mutual position, horizontal and parallel and vertical overlapping distribution of the up and down line tunnel. The sedimentation maximum occurs on the two tunnel center line. For tilted overlapping deployment, the position depends on the mutual position of the up and down line tunnel and has certain deviation. The position of the surface sedimentation maximum deviates to the shallow tunnel.

The Fig. (**4**) shows the horizontal shift around the synchronous evacuating tunnels under three different distribution forms.

The Fig. (**4**) indicates that the horizontal shift maximum around left and right tunnel is 5.08mm and 5.02mm in the horizontal and parallel evacuation and the distortion law is similar. For tilted overlapping distribution, the horizontal shift maximum around the narrow tunnel is 2.92 mm and the horizontal shift maxim around the deeper tunnel is 6.54 mmH. For vertical overlapping, the horizontal shift maximum around the narrow tunnel is 3.76mm and the horizontal shift maximum around the deeper tunnel is 8.52 mm, so the surroundinghorizontal shift maximum for the vertical overlapping distribution is bigger than the horizontal shift maximum in other two distribution forms. For vertical overlapping and tilted overlapping distribution, the deeper tunnel will lead to bigger horizontal shift of the soil. The bigger horizontal shift of two tunnels will occur around the crossing point between the double-hole tunnel center connection line and tunnel perimeter. it indicates that the bigger horizontal shift on the soil on both sides will be caused when the influence on the nearest soil on both sides between two tunnels.

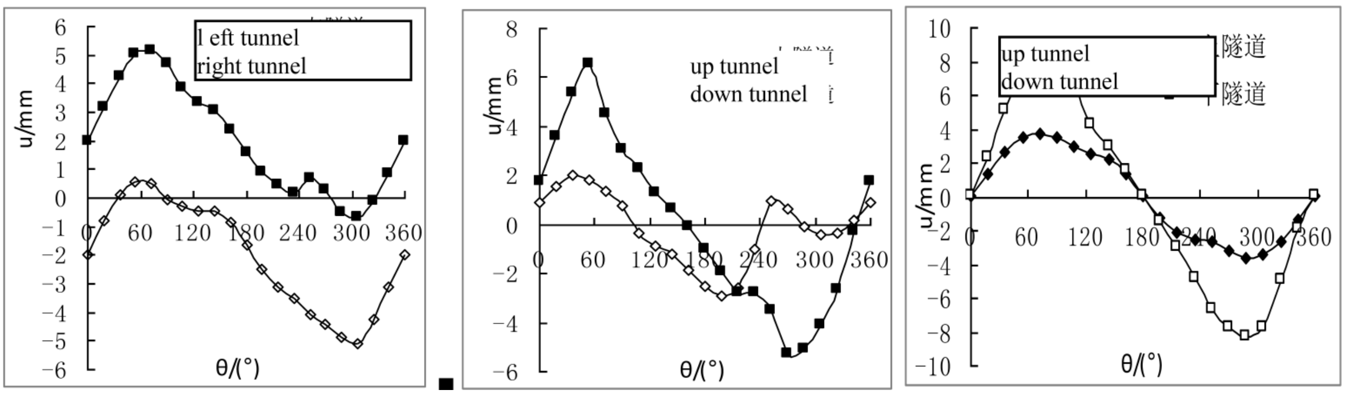
3. INFLUENCE OF DIFFERENT BURYING DEPTHS

The ratio of the burying depth of the tunnel to the gap of the tunnel is within 1.0 and 3.0 in actual double-hole tunnel construction. The parameters and perimeter conditions of the computing model used in this paper are same as them in the above section. Based on the basic model, assume that the diameter D is 6 m, the tunnel gap B is 1D, namely B/D=1.0. four different tunnel burying depth conditions are considered, namely the burying depth H of the up (or left) is 6 m, 9 m, 12 m and 15 m, namely the depth/diameter ratio H/D is 1.0, 1.5, 2.0 and 2.5, which will respectively compute the change law of the peripheral shift and surface sedimentation of the tunnel under different burying depth conditions.

3.1. Parallel Distribution of Double-hole Tunnel

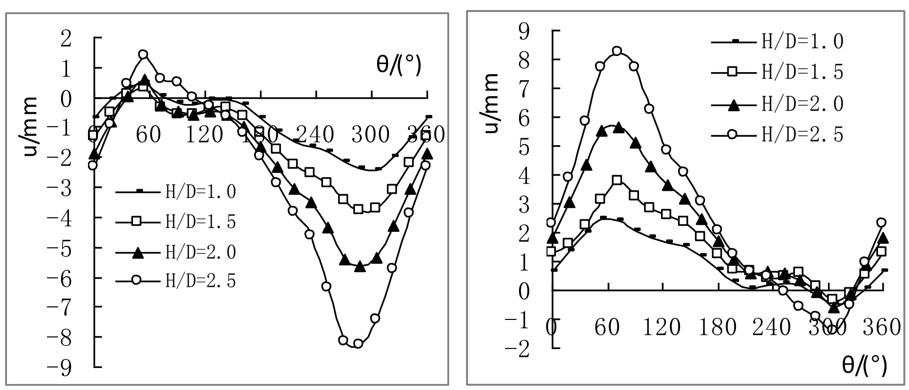
(1) Shift Around Tunnel

The Fig. (**5**) and (**6**) show the horizontal shift curve and vertical shift curve around the tunnel when the



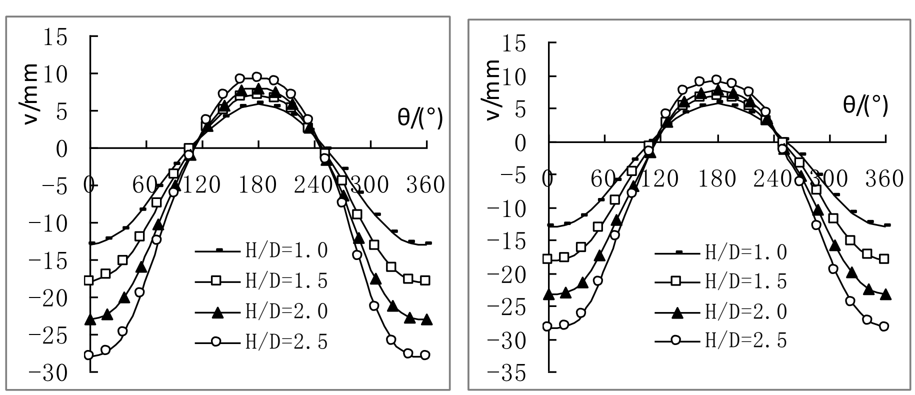
(a) horizontal and parallel distribution (b) Tilted overlapping distribution (c) Vertical overlapping distribution

Fig. (4). Horizontal shift around synchronous evacuating tunnel under three work conditions.



(a) Horizontal shift around left tunnel (b) Horizontal shift around right tunnel

Fig. (5). Horizontal shift curve around double-hole tunnel in case of synchronous evacuation.



(**a**) Vertical shift around left tunnel (**b**) Vertical shift around right tunnel

Fig. (6). Vertical shift curve around double-hole tunnel in case of synchronous evacuation.

synchronous evacuation and other conditions are not changed and the depth/diameter ratio H/D is changed under double-hole tunnel parallel distribution.

The Fig. (**5**) indicates that the horizontal shift maximum of two tunnels occurs at the haunch and the crossing point of the double-hole tunnel center line and tunnel perimeter and the influence on the nearest soil on both sides between two tunnels is maximal. The Fig. (**6**) indicates that the vertical shift around the left and right tunnel will continuously increase with growth of H/D, especially the shift is maximal at the vault and the arch bottom will also have bigger shift. It indicates that the mutual influences of double-hole parallel tunnel will increase and the horizontal and vertical shift around the tunnel will increase with growth of the tunnel burying depth when other conditions are not changed.

(2) Surface Sedimentation

The Fig. (**7**) shows the surface sedimentation curve caused by synchronous evacuation of double-hole parallel tunnel when other conditions are not changed and the tunnel's burying depth is changed.

The Fig. (**7**) shows that the generated maximum surface sedimentation will become bigger with decrease of the tunnel's burying depth and the maximum surface sedimentation will gradually decrease with increase of the tunnel's burying depth. When the burying depth of the tunnel is smaller (H/D=1.0), the surface curve will show "double peak" form. With growth of the tunnel's burying depth, the form of the surface sedimentation curve changes from "double peak" to "single peak". It indicates that the burying depth of double-pole parallel tunnel not only affects the surface sedimentation, but also affects the form of the sedimentation curve. Increase of the tunnel's burying depth will affect reduction of the surface sedimentation. For evacuation of the narrow double-hole tunnel, the proper engineering measures should be taken to reduce the surface sedimentation and avoid the building cracking.

3.2. Vertical Overlapping Distribution of Double-hole Tunnel

(1) Shift Around Tunnel

The Fig. (**8** and **9**) show the horizontal shift curve and vertical shift curve around the tunnels when the vertically overlapped double-hole tunnels synchronous evacuated.

The Fig. (**8**) indicates that the law of the horizontal shift around the up and down tunnel is same. The maximum horizontal shift occurs at the haunch on both sides of the tunnel. With growth of the tunnel's burying depth, the distortion value of two haunch of one tunnel is similar. The horizontal shift around the down line tunnel is bigger than it around the up line because the burying depth of the down

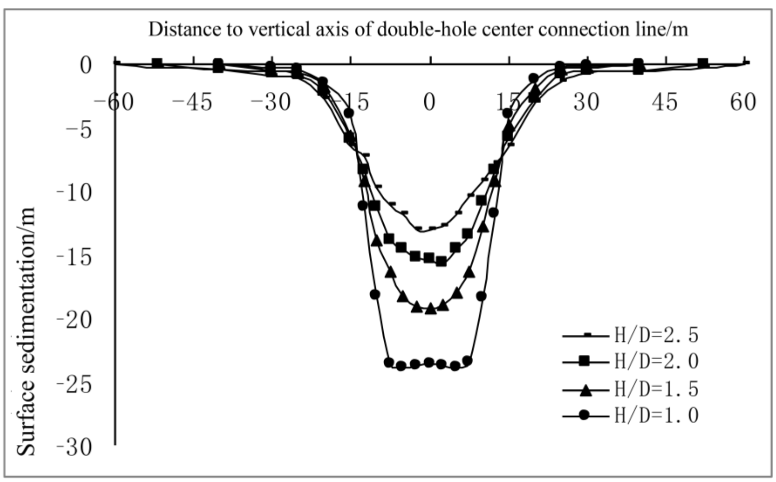
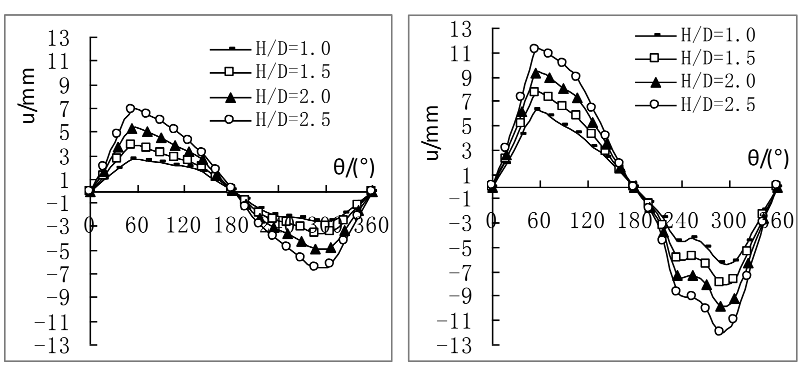
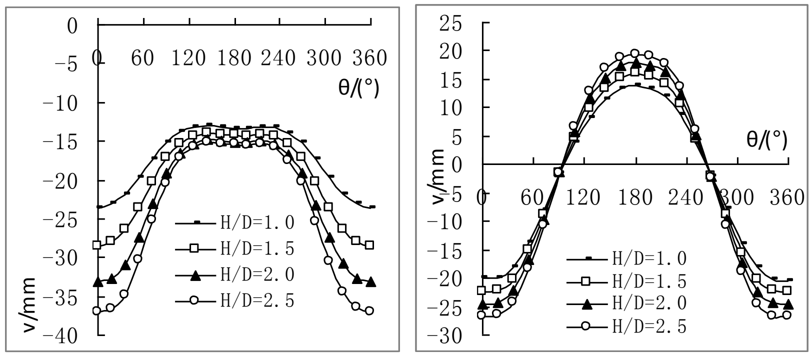


Fig. (7). surface sedimentation curve of synchronous evacuation tunnel under different burying depth conditions.



(a)Horizontal shift around up tunnel (b)Horizontal shift around down tunnel

Fig. (**8**) Horizontal shift curve around tunnel in case of vertical overlapping of synchronous evacuation



(a) Vertical shift around up tunnel (b)Vertical shift around down tunnel

Fig. (9). Vertical shift curve around tunnel in case of synchronous evacuation of vertical overlapping.

tunnel is bigger than it of the up tunnel. With growth of H/D, the maximum shift will also increase. The figure 9 indicates that the swelling and sedimentation will increase around the tunnel with growth of the tunnel's burying depth. The soil around the up tunnel will subside, which is very different from single-hole tunnel evacuation. The arch bottom of the up tunnel will also subside due to influence of down tunnels. The vault of the down tunnel will also generate bigger sedimentation and the arch bottom will lead to certain swelling. The swelling maximum of the arch bottom is less than the sedimentation maximum of the vault. It indicates that the mutual influences of the double-hole vertical overlapping tunnel will increase with growth of the tunnel's burying depth and growth of the horizontal and vertical shift around the tunnel when other conditions are not changed.

(2) Surface Sedimentation

The Fig. (**10**) shows the surface sedimentation curve under different tunnel's burying depth conditions in synchronous evacuation of vertical overlapping distributed double-hole tunnel when other conditions are not changed.

The Fig. (**10**) indicates that the tunnel's burying depth does not affect the feature of the surface sedimentation curve, is same as the single-hole tunnel evacuation, and shows as "single peak". With growth of the tunnel's burying depth, the surface sedimentation will also increase. For H/D=1.0, the maximum surface sedimentation is 29.71 mm. For H/D=2.5, the maximum surface sedimentation is 20.67mm and the burying depth will increase by 2.5 times. The maximum surface sedimentation will reduce by about 30%. It indicates that growth of the burying depth will reduce the surface shift and distortion to some extent for vertical overlapping tunnels, but it will not affect the form of the sedimentation curve.

3.3. Tilted Overlapping Distribution of Double-hole Tunnel

(1) Shift Around Tunnels

The Figs. (**11** and **12**) show the horizontal shift curve and vertical shift curve around the tunnels in the synchronous evacuation of tilted overlapping double-hole tunnel when the tunnel's burying depth is changed and other conditions are not changed. The law of the shift around the tilted overlapped tunnels is same as it of the above two distribution. Notice that the maximum horizontal shift around the up tunnel will change due to influence from the down tunnel evacuation and will occur

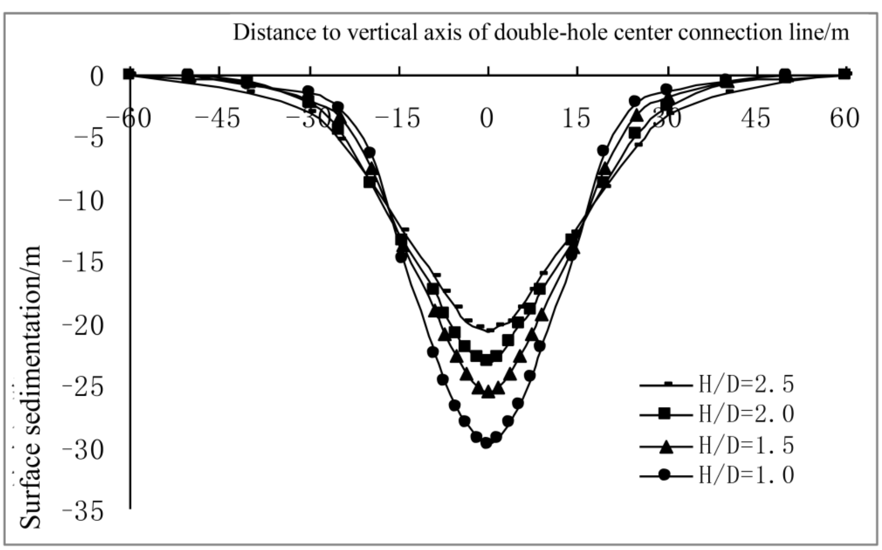
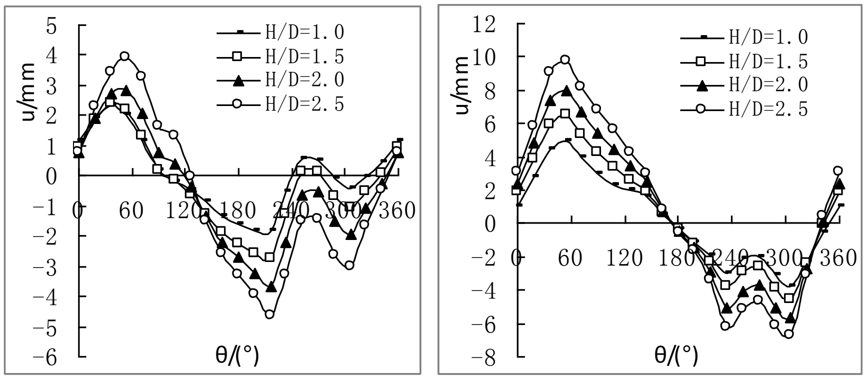
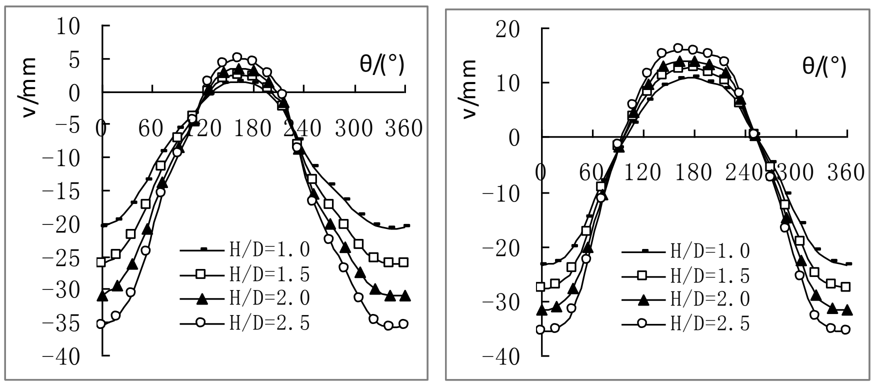


Fig. (10). Surface sedimentation of synchronous evacuation tunnels under different burying conditions.



(a) Horizontal shift around up tunnel (b) Horizontal shift around down tunnel

Fig. (11). Horizontal shift curve around the tilted overlapping tunnel in case of synchronous evacuation.



(a)Vertical shift around up tunnel (b)Vertical shift around down tunnel

Fig. (12). Vertical shift curve around the tilted overlapping tunnel in case of synchronous evacuation.

at 216°(namely crossing point between two-hole tunnel center connection line and up tunnel boundary).

(2) Surface Sedimentation

The Fig. (**13**) shows the surface sedimentation curve generated by evacuation of the tilted double-hole tunnel when the tunnel's burying depth is changed and other conditions are not changed. It indicates that the sedimentation law of the tunnel's surface is same as it in horizontal distribution and vertical distribution. The surface sedimentation maximum occurs on the left side of the vertical axis of the double-hole tunnel center connection, namely position close to the up line. For H/D=1.0, the maximum surface sedimentation is 27.86mm.

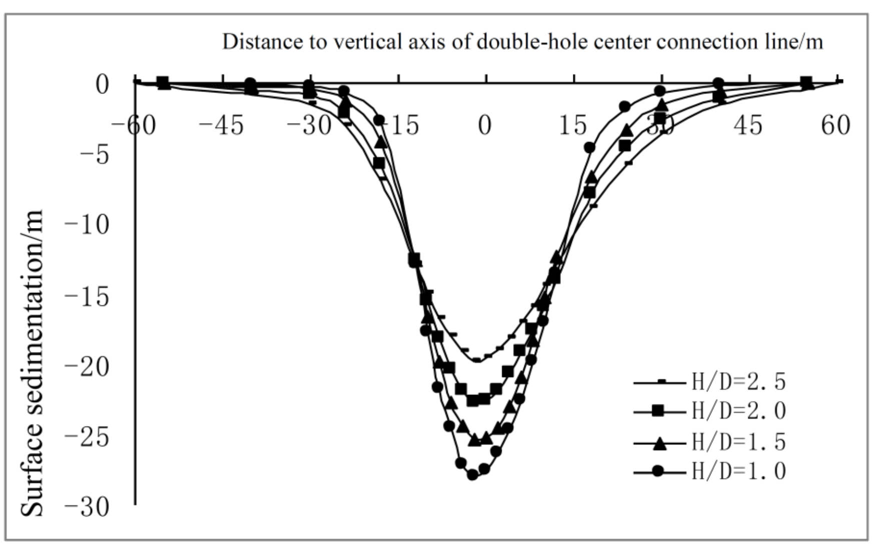


Fig. (13). surface sedimentation curve of synchronous evacuation of double-hole tunnel under different burying depth conditions.

For H/D=2.5, the maximum surface sedimentation is 19.72mm. It indicates that the burying depth has certain influences on the surface sedimentation of the tilted overlapped double-hole tunnel. growth of the burying depth will play a certain role on reduction of the surface shift and distortion.

4. INFLUENCES OF DIFFERENT GAPS

4.1. Parallel Distribution of Double-hole Tunnel

(1) Shift Around Tunnel

The tunnel's burying depth H is 1.5D, namely H/D=1.5. The horizontal shift and vertical shift around the tunnels is computed in case of synchronous evacuation by changing the gap between double-hole tunnel. B is 6.0m, 9.0m, 12.0m and 15.0m, namely B/D=1.0, 1.5, 2.0 and 2.5. The computing results are shown as the Fig. (**14** and **15**).

Shown as the Fig. (**14**), the maximum horizontal shift around two tunnels has haunch and the vault and arch bottom of two tunnels will experience the bigger vertical shift. Growth of the tunnel gap will increase the horizontal shift around the tunnels under same burying depth. When the gap of the tunnels is over a value, the horizontal shift of the left and right tunnel is similar to it in case of single-hole tunnel evacuation, which indicates that growth of the tunnel gap will reduce mutual interaction between tunnels.

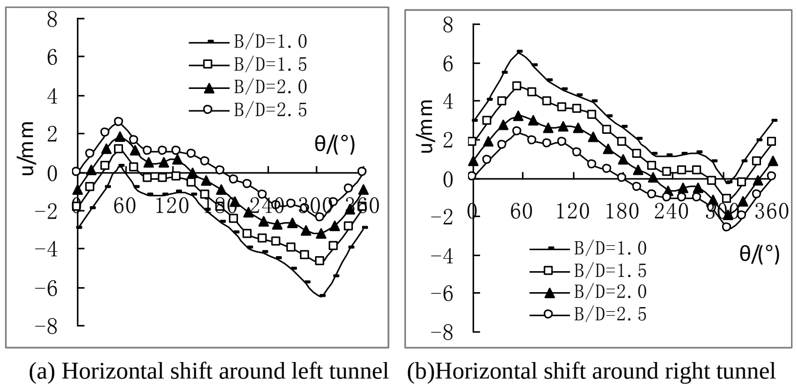


Fig. (14). Horizontal shift curve around parallel distributed tunnel in case of synchronous evacuation.

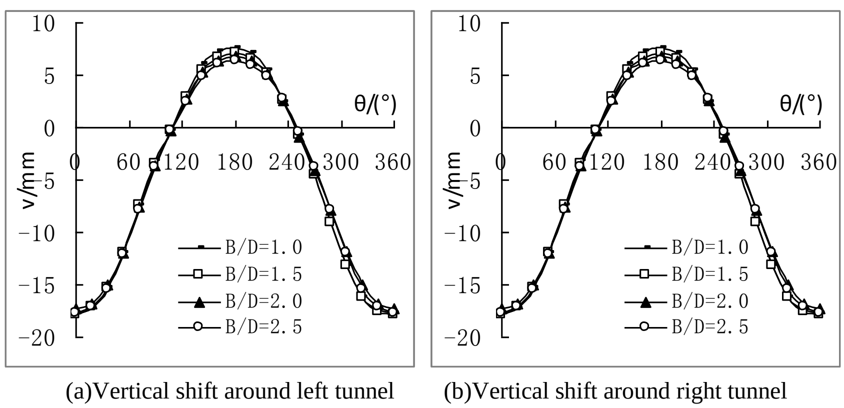


Fig. (15). Vertical shift curve around parallel distribution tunnel in case of synchronous evacuation.

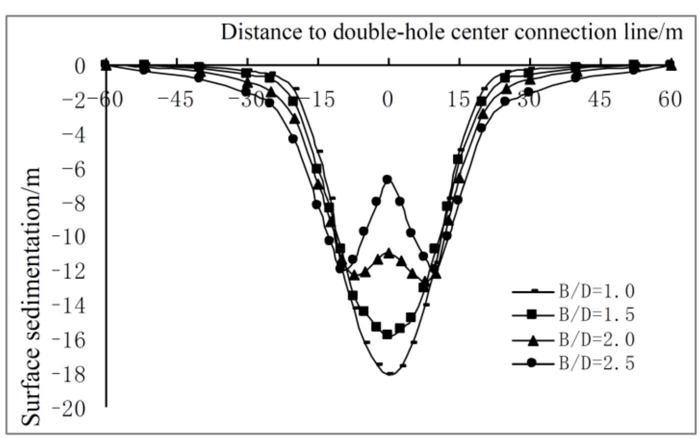


Fig. (16) surface sedimentation curve of synchronous evacuation of double-hole tunnel under different burying depths.

The Fig. (**15**) indicates that the vertical shift around the tunnel does not change with growth of the tunnel gap, which indicates that growth of the tunnel gap will seldom affect the vertical shift of the left and right tunnel.

The Fig. (**16**) indicates different surface sedimentation curves generated by evacuation of double-hole parallel tunnel at different gaps.

The Fig. (**16**) indicates that the maximum surface sedimentation will increase with decrease of the tunnel gap and the surface sedimentation curve will gradually transit from "double peak" to "single peak" when other conditions are not changed. In addition, the bigger distance of evacuation gap of two tunnels will indicate bigger scope of influences on the surface, namely the surface sedimentation groove caused by evacuation will become wider. For B/D=2.5, the width of the sedimentation groove is 40m. For B/D=1.0, the width of the sedimentation groove is 60m. Computing indicates that the surface sedimentation above two tunnels is very similar to the surface sedimentation caused by single-hole tunnel evacuation when the gap of two tunnels is over 5D.

4.2. Vertical Overlapping or Tilted Distribution of Two Tunnels

For the vertical overlapping distribution of double-hole tunnel, this paper will fix the down tunnel at the 36 m position under the surface in computing and change the gap of the up and down tunnel by changing the burying depth of the up tunnel, shown as the Fig. (**17**).

When the position of the fixed down tunnel is not changed, change the gap of the up tunnel and down tunnel and the burying depth of the up line will also change. The influence of the burying depth on the shift around the tunnel is discussed in the above chapter, so this section only discusses the influence of the surface sedimentation under this distribution conditions. The figure 18 indicates the surface sedimentation curve when the gap of the up line and down line is changed and the burying depth of the down line is not changed.

The Fig. (**18**) indicates that the bigger gap of two tunnels will increase the maximum surface sedimentation under vertical overlapping. Regardless of change of the gap between tunnels, the maximum position and curve feature

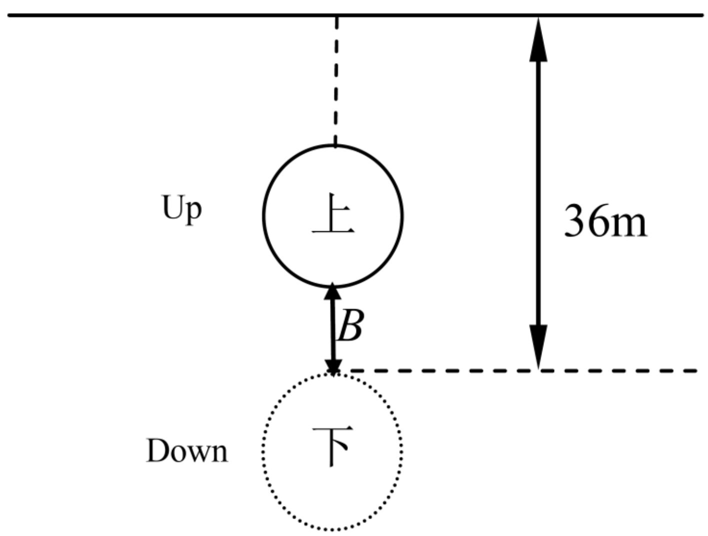


Fig. (17) Tunnel distribution form.

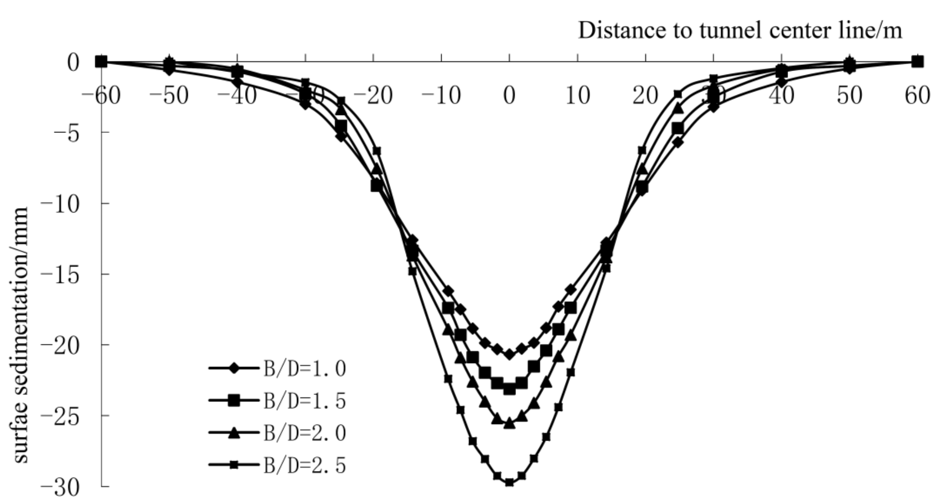


Fig. (18). surface sedimentation curve of synchronous evacuation of double-hole tunnel under vertical distribution.

of the tunnel sedimentation will not change, namely the maximum surface sedimentation will occur above the center line of two tunnels. The curve is shown as “single peak”. with growth of the tunnel gap, the influence range of evacuation on the surface will become bigger, namely the surface sedimentation groove caused by evacuation will become wider. The analysis indicates that it is caused by change of the gap of the vertical tunnels, namely the burying depth of the up tunnel. The bigger gap will indicate smaller burying depth of the up line, bigger surface sedimentation and increased influence width of the surface sedimentation groove. The law of the soil layer shift and surface sedimentation around the tilted distributed tunnels is equivalent to “middle” state between the horizontal distribution and vertical distribution, so the tunnel of the tilted distribution will not be analyzed in detail. Compared to the parallel distribution and vertical overlapping distribution, the maximum horizontal shift and maximum surface sedimentation of the tilted overlapped tunnels will change.

CONCLUSION

This paper simulates and analyzes the law of the surface sedimentation and soil distortion around tunnels in synchronous evacuation of double-hole tunnel in three different distributions by using finite element analysis software MIDAS/GTS v2.01, compares and analyzes several important factors in double-hole tunnel evacuation such as tunnel distribution, different tunnel gap and different tunnel burying depths, and concludes the following conclusions.

For horizontal distribution, vertical distribution and tilted distribution of two tunnels, the vertical distribution has the biggest influence on tunneling, followed by the tilted distribution. The horizontal distribution has the smallest influence. With growth of the tunnel gap, the mutual influence between two tunnels will reduce. with growth of the tunnel’s burying depth, the influence on tunneling will become bigger.

CONFLICT OF INTEREST

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

ACKNOWLEDGEMENTS

This paper is written under the guidance of professor Xunneng Gao from Huaqiao University and professor Fuquan Chen from Fuzhou University. Thank for them!

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Received: September 17, 2014 Revised: December 17, 2014 Accepted: December 23, 2014