Study on land subsidence law of shield tunnel overlying karst

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Abstract: In the process of tunnel construction, underground karst is one of the main causes of ground collapse accidents. Using the GTS/NX finite element software, the numerical analysis of karst with different shapes and locations is carried out, and the law of surface subsidence caused by the karst overlay on the tunnel is obtained, which provides the basis for the deformation of the stratum where the karst cave is located, the prediction of accident, the risk assessment and the formulation of the treatment scheme.

1. Introduction
In recent years, in the process of subway construction in China, ground collapse engineering accidents have occurred from time to time, causing huge loss of life and economic property. Through investigation, it is found that underground cavity is one of the main causes of ground collapse accidents. The underground geological situation is complex, the karst develops irregularly, the rock properties around the cavity are unstable, and the tunnel and subway are faced with construction safety problems due to the influence of underground pipeline leakage and surface construction disturbance[1-2]. Therefore, it is necessary to study the law of surface subsidence and the characteristics of stratum failure caused by karst.

In the process of karst tunnel construction, the holes on the surface subsidence and tunnel in formation damage problem have caused wide concern. Some scholars do related research in the hollow of stratum deformation effects. Cai Yi et al. by FLAC3D to hole size and influence on the formation of hollow and tunnel net spacing are studied, It is concluded that there is a "critical net distance" between the cavity and the tunnel, and the surface subsidence corresponding to the "critical net distance" is the minimum value of the surface subsidence under the influence of the cavity [3]. Song Zhanping adopted the numerical test method to obtain the rule that the displacement of tunnel vault will be increased when the distance between the overlaying karst cave and tunnel is less than 1.0d, while the displacement of tunnel vault will be decreased when the distance is greater than 1.0d [4]. Through numerical analysis, Yi Jiemin obtained the change law of deformation of surrounding rock in different positions around the tunnel, in the presence of soil caves and karst caves at different sides of the tunnel [5]. Cai Yi et al. carried out numerical simulation and model tests on voids at different locations and found that, compared with the situation without voids, the width and depth of subsidence groove of the surface settlement curve above the voids were different under the influence of stratum voids, and the settlement curve would shift with the change of the position of voids [6]. Liu Daoyan et al. adopted the three-dimensional finite element numerical analysis method and concluded
that the karst caves around the tunnel only within a certain range from the tunnel had a great influence on the stability of shield tunnel construction [7].

Most of the existing research results focus on the single aspect of karst cave, which is difficult to provide a theoretical basis for the deformation of karst cave strata, accident prediction, risk assessment and the formulation of treatment plan. Therefore, this paper takes karst cave as the research object, relying on Jinan subway engineering project and using GTS/NX finite element analysis software. The influence of different shapes, different horizontal positions and different vertical positions of karst caves on surface subsidence was studied. It is of great significance to the formation deformation, accident prediction, risk assessment and treatment plan formulation of karst cave in the tunnel construction process.

2. Project summary
The second section of Jinan rail transit line R3 starts from Mengjiazhuang along the west side of Longding Avenue to the north near the armed police fire brigade, crosses Daxin River and mountains, and ends at the intersection of Jingshi Road and Aoti West Road. The total length of the two lines is about 5.6 km, and the buried depth of the arch is about 13.45 ~ 19.77m.

According to the regional geological data, the proposed section is a piedmont alluvial plain landform, the terrain gradually decreases from south to north, and the surface elevation of the orifice is 104.63-125.93m. In the depth of site investigation, the Quaternary strata are mainly exposed, and the soil is mainly filled with soil, silty clay and silty clay containing gravel. The rock strata are mainly marl and moderately weathered limestone, among which the shield section of this section crosses through the moderately weathered limestone strata for a long distance. The 21-2-1 layer of medium-weathered rock is mainly composed of calcite. The joints and fissures are developed, and the core is broken into fragments. The layer is discontinuous in distribution.

3. Law of surface subsidence and failure
In order to study the influence of karst vertical shape on land subsidence, karst can be divided into the following three types by taking the same vertical area:

Vertical and lateral extensions are similar, and the cavity with the aspect ratio between 0.75 and 2 is approximately regarded as a circle, as shown in the figure of working condition 2.

The vertical direction is relatively long, and a number of voids are interconnected with each other. Barrel-shaped voids with a height to width ratio greater than 2 are approximately regarded as longitudinal ellipses with a long vertical direction, as shown in the figure of Working Condition 3.

A disk-shaped cavity with a long transverse direction and a short vertical direction, with multiple voids interworking with each other, and a height to width ratio lower than 0.75, is approximately regarded as a long transverse ellipse. As shown in the figure of working condition 4, the absence of karst caves in the overhanging strata of the tunnel is taken as working condition 1.
In order to explore the influence law of karst cave shape on surface subsidence, four working conditions of no karst cave, circular karst cave, transverse elliptic karst cave and longitudinal elliptic karst cave were established. The vertical area of each karst cave (8m²) was the same as that of the net distance of tunnel vault (2m).

By analyzing the numerical simulation data, it can be found that the tunnel overlying cavity will aggravate the ground subsidence. The shape of voids also affects the maximum surface settlement. Under the same vertical area of voids, the transverse elliptical voids have the greatest influence on the surface settlement, followed by the circular voids, and the longitudinal elliptical voids have the least influence.

In order to explore the influence of the horizontal position of the karst cave on the surface settlement, the transverse elliptical karst cave with the largest influence on the surface settlement was taken as the research object. Three working conditions were established for numerical calculation and analysis, which were located directly above the left tunnel, left tunnel and above the middle of the two tunnels. The surface settlement effect was shown as follows.
The results show that the horizontal position of the cavity has a significant effect on the surface subsidence, and the surface subsidence is greater when the cavity is located on one side of the tunnel than when the cavity is directly above the tunnel. Due to the oblique development of the plastic zone of the soil, when the cavity is located on one side of the tunnel, the plastic zone of the two soils will develop continuously and gradually connect into one, which will cause greater damage to the soil and increase the surface settlement. When the cavity is located in the middle of the two tunnels, the plastic zone of the two tunnels is connected with the plastic zone of the cavity, and the soil damage is deeper and the surface settlement is more.
To explore the influence of the tunnel and the hole distance on the surface subsidence, take effect obvious horizontal elliptical as the research object, the hole directly above the tunnel respectively 2.0 m, 3.5 m, 5.0 m three kinds of conditions are numerically simulated, results show that the surface subsidence with the increase of overlying voids and tunnel distance has increased after the first reduce rule, which shows that in the vertical direction, There is a "critical net distance" which minimizes the effect of the void on the surface subsidence.

4. Conclusion
The upper cavity will increase the surface subsidence and cause the surface sag. From the perspective of the shape of the cavity, the transverse elliptical cavity has the most significant effect on the surface subsidence, followed by the circular cavity and the longitudinal elliptical cavity. From the horizontal point of view, when the cavity is located in the middle of two tunnels, the surface subsidence is the largest, and the influence of the cavity directly above the tunnel is small. In the vertical direction, the ground subsidence decreases first and then increases with the increase of the vertical distance between the cavity and the tunnel. Among the above three influencing factors, the horizontal position of the cavity has the most significant influence. This law can provide a theoretical basis for the prediction, evaluation and formulation of the treatment plan of the cavitation stratum disaster accident, and make the cavitation management more economic and reasonable.

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