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Stratum Displacement Law and Intelligent Optimization Control Based on Intelligent Fuzzy Control Theory During Shield Tunneling

Chibawe Musa, Baoping Zou,
School of Civil Engineering
Zhejiang University of Science and Technology, Hanzghou, CN

Abstract
The laws of Stratum displacement and optimal control are critical for shield operation. This article's focus is made on the intelligent fuzzy control theory concentrating on earth pressure, total thrust, driving speed, cutter torque, grouting pressure and grouting volume as the main elements of the study. A model of intelligent fuzzy control theory based on the model of No. 9 Line of Guangzhu Rail transit, on the Tianma river shield section. The paper also analyzes stratum displacement law due to shield tunnelling, executes & analyses intelligent controls for optimization of parameters, combining the five two-dimensional structures of the double structure of fuzzy control system. According to the observations made on the model. The model is upto date and the control of all parameters develops stably. The parameter ranges should be controlled as follows: earth pressure, 0.19 ~ 0.22Mpa; total thrust, 1100 ~ 1350T; driving speed, 38 ~ 50mm / min; cutter torque, 1600 ~ 2300 KN • m; grouting pressure, 0.19 ~ 0.25Mpa and grouting volume, 30 ~ 50L/min.
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1. Introduction

In recent years, with the gradual expansion of urban areas and the growth of the urban economy, China's urban subway construction has advanced. The shield, as a major subway construction engineering approach, has had wide application on previous projetcs in Hangzhou, Shanghai, Beijing, Guangzhou and other cities. However, any underground excavation and construction projects, regardless of their size and depth, would inevitably disturb the original formation and stress field, causing stratum displacement, endangering the safety and stability of subsurface structures, road, rail and pipeline further, and resulting in environmental degradation. (Ran-L, 2014); Reports the structure and layout of the shield construction of metro tunnels. It also presents the procedure for ground stabilisation by freezing and construction of the metro-tunnel cross-passages in respect to the design and construction principles in metro infrastructure monitoring for the shield tunnel observation intervals, with respect to Metro Line 1, in Hangzhou. Exploration of the Shield tunneling and environment protection in Shanghai soft ground, (Ijaz Ahmad, 2019). Shield construction results in soil disturbance and it takes a very long time to stabilize. With soils inert properties of high sensitivity, high water content and thixotropy, the resulting soil stiffness degradation impacts the future generation of ground-borne traffic vibration and it's propagation to the foundations of nearby buildings, (Armaghani R. S., 2019).

Several research on stratum displacement resulting from shield tunnels construction have been undertaken by domestic and foreign scholars to aid engineers in the planning, design execution and safety operation of shield tunneling system. (Zhao Li, 2019); Studied the effect of shield tunneling on soil deformation. (Xiongyao Xiea, 2018); developed an interactive platform for settlement control during shield tunneling. (Cheng Zhoua, 2019); Introduced, Complex Network (CN) theory to get the topological relations and network structure of the monitoring parameters. Using the network topology, Spectral Clastering (SC) is applied in classifying the data, for the Yangtze river-crossing tunnel in China. (Jie Wang, 2019); established that effects of vertical ground motion tends to increase the maximum values of the peak and residual dynamic joint openings, which can be considered during seismic design of shield tunnel, (Park, 2014). (Grasmick, 2017); Investigated Surface settlement prediction for EPB shield tunneling in sandy ground. (Quanmei Gonga, 2018); modelled a test system to simulate the tunnel uplifting process at varying Tunnel depth. (Zhu , 2017); Studied the control of surface settlement by considering shield tunneling technology based on Maximum Surface Settlement (MSS) and allowable partial, incline curvature of settlement trough for Xi'an Subway line No. 2. (Jinxing Lai, 2016);. Based on the random medium theory, (D. Bouayada, 2017); Studied, ground settlements caused by shield tunneling with respect to the operational and geological parameters using the hybrid PCA/ANFIS method. (JinxingLai, 2016); established a model using artificial neural network for predicting the surface deformation during shield tunnel construction, at the front and rear measuring point and summarized the research challenges in deformation prediction using ANNs.

All the reviews are based on the extensive research of stratum displacement caused by shield tunnel construction. Theoretical frameworks for the research are empirical formulae, random medium theory, model test theory, finite element theory and artificial neural network theory. However, the related research, home and abroad, on stratum displacement induced by shield construction based on intelligent fuzzy control theory is limited. (Mushiri, 2017) applied Fuzzy Logic on a Processing plant's Critical Control and Monitoring parameters. (Zhang, 2019); Proposed a traffic control method called generic real-time optimal contraflow. (Arsalan Mahmoodzadeh, 2019); introduced ideas and methods of the discipline of intelligent control and established deformation model of an intelligent fuzzy logic control system by using fuzzy logic control technology. Based on the site test in shield tunnelling and using fuzzy math methods, Song et al. (2009); studied discrimination theory and methods of tunnel rock status under shield tunnelling conditions based on drainage tunnel project in Chongqing.

Foreign research is mainly according to the problems of the tunnel intelligent ventilation and risk. Domestic research is limited to tunnel deformation and rock evaluation in Shanghai, Nanjing and other districts. Currently, there are no studies based on Shenzhen in the Tianma River Delta plain. Moreover, a lot of sea tunneling projects in varying soils and geotechnical strata have been carried out in Guangzhu over the years. Despite, the significant experience from many projects in industry, the phenomena caused during tunneling with the Tunnel Boring Machine is not sufficiently understood (Mohammed Beghoul, 2019),. With its complex geology mostly in weak watery stratum. The engineering problems faced by Guangzhu during the subway construction in soft soil faced are unique. (Chen X Z. B., 2011). Besides, Shenzhen does not have many records of successful engineering experience in shield tunnelling beneath Binhai road to ensure its success. The entire construction of the Shenzhen Metro could be impacted greatly by the success of the shield through Binhai Road. Therefore, introducing intelligent fuzzy control theory to study the shield tunnel construction is an inevitable trend of guiding the construction of intelligent information. In this paper, HouHai-KeYuan shield section of Shenzhen Metro Line 2 beneath Binhai Road is analyzed by selecting earth pressure, total thrust, driving speed and other factors as the main objects of the study to establish a model of intelligent fuzzy control theory. It also analyzes stratum displacement law due to shield tunnelling, controls the intelligent optimization of parameters and combines the five two-dimensional structure of the double structure of the fuzzy control system. This paper has a very significant referential function to the design and construction of tunnels.

2. Establishment of the Model of Intelligent Fuzzy Control Theory

Intelligent fuzzy control seeks to establish a quantitative and qualitative analysis of the ground deformation control in shield tunnelling and imitate human cognitive thinking for reasoning referred to as intelligent control. Effectiveness of intelligent control is closely related to the controllable parameters in shield tunnelling, and the parameters in shield tunnelling are the main factors influencing stratum displacement in shield tunnelling. The selected parameters of this study are; earth pressure, total thrust, driving speed, cutter torque, grouting pressure and grouting volume as the main objects of the study to establish a comprehensive model for intelligent fuzzy control. The paper also tries to determine the input of the control parameters and fuzzy controller design, combining the five stages of surface settlement in shield tunneling, ((D. Bouayad, 2017)). Fig.1 is the structure of the intelligent fuzzy control system. The input of control objectives and parameters in shield tunnelling are quantitative data, including the early accumulated knowledge and experience in shield tunnelling. But the implementation of qualitative information transmission through obfuscation, fuzzy control reasoning, clarity and other algorithms should be achieved in the process of control to achieve the interaction among human intelligence, data and information, and then to optimize control of surface deformation, (Arsalan Mahmoodzadeh, 2019).

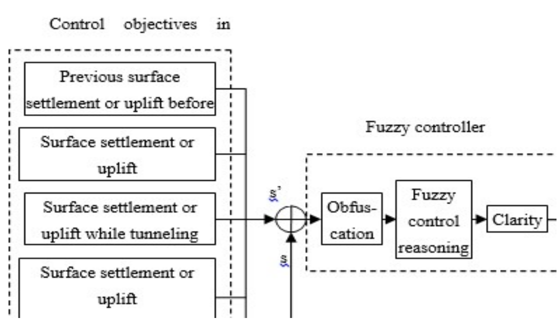

Fig.1. Structure of intelligent fuzzy control system

2.1. Determination of Control Parameters in Input and Output

The determination of control parameters in the input is combined with the four stages of surface settlement in shield tunnelling (HongZhan Cheng, 2019). They are:

（1）Surface settlement or uplift before shield tunnelling

This is mainly caused by the movement of the original soil induced by squeezing of soil in front of the shield leading to loss of formation. Shield tunnelling causes stress redistribution and stress release around the soil in shield tunneling and results in slip surface. The groundwater is also lowered by shield tunnelling, resulting in consolidation settlement with the increased effective stress of formation. During the shield tunneling, the thrust is too large or too small and the soil stress releases, there is an imbalance of the earth pressure around the excavation (cutter), which then results in surface uplift or settlement. The maximum deformation value s1 of monitoring site 1 of early settlement or uplift before shield tunnelling and its changing value over time ds1 are put in a group of input.

（2）Surface settlement or uplift while at the shield head and Soil interface

As the shield machine passes a point, the soil deformation increases rapidly causing uplift or settlement. This phenomenon results in high volume loss coming from the bead for overcutting. In order to mitigate the effect of friction between the soil the Earth Pressure Boring shield, the bead is attached on cutter head. The cutter torque directly affects rate of soil destabilization and removal from the excavation face. Which then results in surface uplift or settlement. The maximum deformation value s2 of monitoring site 2 of early settlement or uplift at shield tunnelling face and its changing value over time ds2 are put in a group of input.

（3）Surface settlement or uplift while tunnelling

As a separate input, the settlement during shield tunneling is a dynamic process with strong real-time control. This is mainly because the shield has to overcome the soil friction in shield tunneling, including friction between the shield shell and the soil, comprehensive resistance of earth pressure, the resistance induced by shield precursor and water pressure, the frictional resistance between the segment and the shield tail, thus resulting destruction of soil strength, changing the stress balance of the original soil. Therefore, the maximum deformation value s3 of monitoring site 3, and its changing value ds3 over time are put in a group of input. (Jin Dalong, 2019).

（4）Surface settlement or uplift induced by the gap of the shield tail

The maximum deformation value is given as s4, for monitoring site 4, and its changing value ds4 over time. Before the segment falls off the shield tail, there is binding force of the soil from the shield, pointing towards the soil and when the shield tail falls off, there is gap between the shield and soil. If the shield is not promptly filled out, or grouting is insufficient, or pressure is too small, it will lead to hollow section reducing inward, causing soil stress release, force release, and then leading to surface settlement. On the contrary, if there is excessive grouting or excessive pressure, surface uplift is caused. (Jin Dalong, 2019)

（5）Long-term settlement after shield tunnelling

The reason for putting the maximum deformation value s5 of monitoring site 5, and its changing value ds5 over time is that the settlement is mainly caused by the consolidation deformation and the creep deformation. In the soil of soft plastic and plastic flow with high void ratio and sensitivity, this distortion is particularly obvious, and the settlement often goes through a long time, (Fan-yan Meng, 2018), (Zhi-Feng wang, 2019). The determination of the output controlling parameters is mainly based on the control of the earth pressure, total thrust, driving speed, cutter torque, grouting pressure and grouting volume.

2.2. Structure of an Intelligent Fuzzy Control System

Combining the determination of the output and input of control targets of the five stages with surface settlement caused by shield construction, this paper will divide deformation system in shield tunneling into control subsystem of stratum displacement in earth pressure, control subsystem of stratum displacement in total thrust, control subsystem of stratum displacement in driving speed, control subsystem of stratum displacement in cutter torque, control subsystem of stratum displacement in grouting pressure and grouting volume. Each system uses the two-dimensional structure of a double structure of a fuzzy control system (Arsalan Mahmoodzadeh, 2019). The structure of a deformation fuzzy controller is shown in Fig. 2.

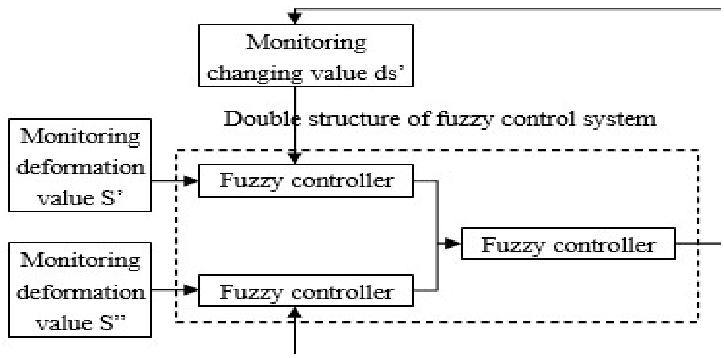

Fig.2. Structure of deformation fuzzy controller

2.3. Establishment of the intelligent fuzzy control system

To establish the intelligent of this system, data is compiled using the MATLAB 7.0, and the fuzzy inference systems of Mamdani which include the fuzzy of input, fuzzy operators, fuzzy reasoning, clustering output and anti-blur (Juang, 2015, (Mushiri, 2017); simulated under Matlab software, the boiler: oil level, pressure and temperature using the programmable logic controller (PLC) with a fuzzy logic controller as the main brain of control. (S.N. Vassilyeva, (i, ii,) 2017), (Kaveh Ahangari, 2015); applied modern intelligent methods to predict subway settlement of tunnel future levels. For deformation value and variation value of the controlling and monitoring points, it is determined using [-4 4] as the universe, and the fuzzy subsets are {NB NM NS ZO PS PM PB}. As for the output and control values, they are divided based on the engineering experience and experimental data universe, and the fuzzy subsets are {NB NM NS ZO PS PM PB}, with NB, NM, NS, ZO, PS, PM and PB denoting respectively negative big, negative, negative small, zero, positive small, positive, and positive big. ((S.N. Vassilyeva, (i, ii), 2017); (Mushiri, 2017); (Xiaofei Li, 2019)). The membership function used is Gaussian membership function, leading to the membership function of deformation value E, change value EC, and control value U (E is ds'; EC is ds '' and U is the output of the control target), which is shown in Fig. 3.

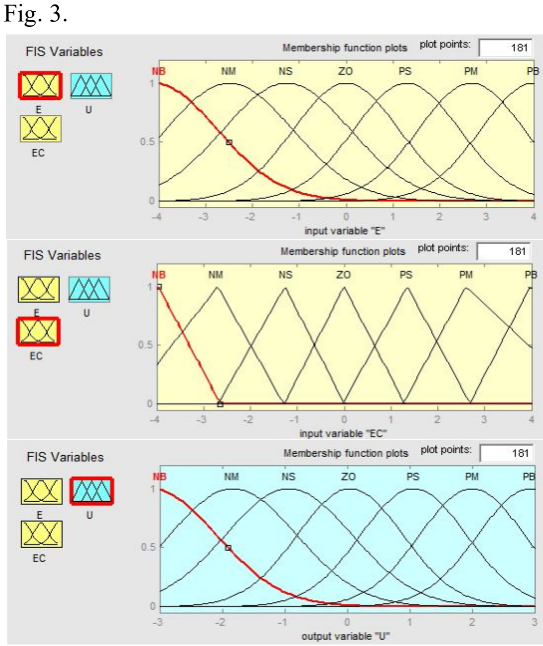

Fig.3. Variable membership function

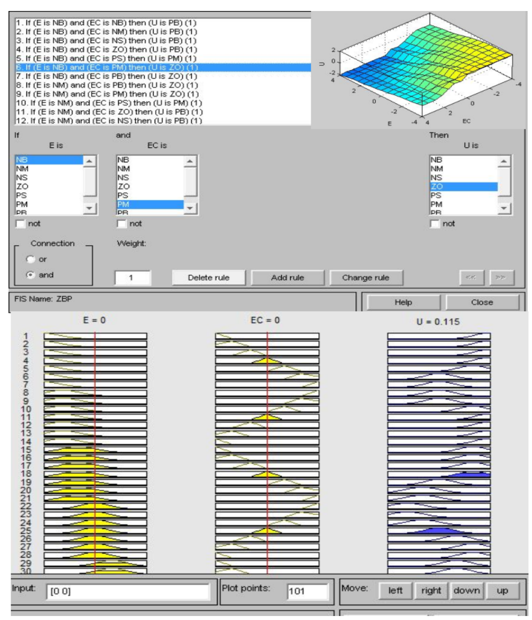
Fig.4. Fuzzy inference control system and map of characterized surface observation

Fuzzy control rules, with a large number of experimental data and experience, are summarized as follows: the two input variables E and EC each has seven language values using "if ... then ..." conditional statements. Therefore, there is a total of 49 fuzzy rules used which then process the output of the reasoning process in an anti-blur way, establishing the intelligent fuzzy inference control system, which is shown in Fig. 4.

3. Stratum Displacement Law of the Intelligent Fuzzy Control

To analyze the availability and effectiveness of stratum displacement of the model of intelligent fuzzy control. A case study of the HouHai-KeYuan shield section of Shenzhen Metro Line 2 beneath Binhai Road is analyzed. The shield section is 1220.46m in length, and the excavation diameter, φ6.28m. The tunnel width from left to right is 9.2 ~ 12.2m, and the thickness of covering soil is 14.25 ~ 17.50m. The shield is ZDK9 892.500 ~ ZDK10 45.000 beneath Binhai Road in mileage, passing through the road twice. Binhai Road is a main road connecting Futian and Luohu District, and an important natural landscape belt off coast in Shenzhen. The area that the shield passes through is of complex formation. Being a reclamation, the area has sand (gravel) quality clay strata that are good in permeability and water-richness. The uneven distribution of the strata thickness is easy to soften under the action of groundwater, which leads to the low stability of the shield.

First, the left line is constructed, and then the right one. Because constructing the left line has moved the soil around the tunnel on the right line, this paper selects the right line beneath Binhai Road as the main study site to verify the **availability** of the model of intelligent fuzzy control effectively. The research objects include earth pressure, total thrust of which **105 sets** of data are used as a reference within **1.5m** for each ring. Combining with the main control monitoring points of **31 sets of data**, this paper analyzes the stratum displacement law induced by shield construction comprehensively.

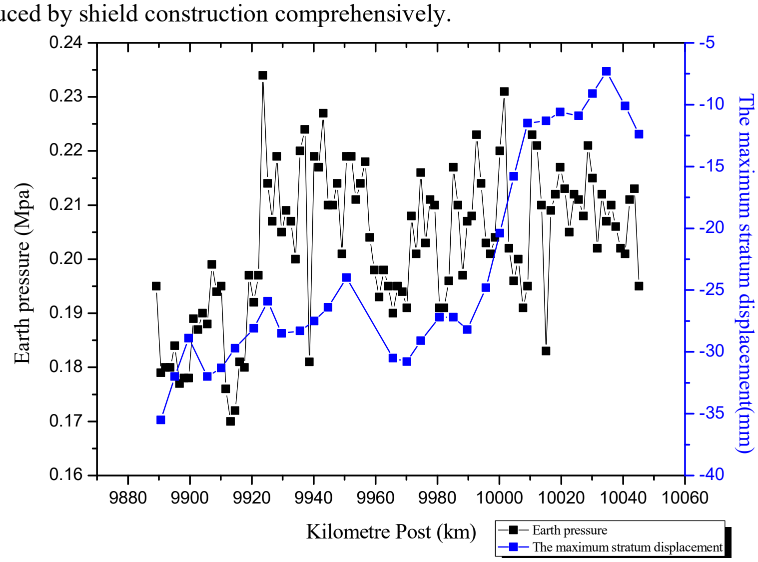

Fig.5. Comparison between the maximum stratum displacement and intelligent control of earth pressure

3.1. Stratum Displacement Law of Control Subsystem of Stratum Displacement in Earth Pressure

Fig. 5 is the comparison between the maximum stratum displacement and intelligent control of earth pressure. It can be seen that the earth pressure control is good and the real-time control is very strong. In mileage of ZDK9 895 ~ ZDK10 000, 79% of the earth pressure is 0.19 ~ 0.22Mpa and 75% of the surface settlement, -20 ~-30mm deep. In mileage of ZDK10 000 ~ ZDK10 045, 97% of the earth pressure is 0.19 ~ 0.22Mpa and other surface settlement, less than-20mm. The maximum earth pressure is in mileage of ZDK9 923.65 being 0.234Mpa and the minimum, mileage of ZDK9 913.15 being 0.17Mpa. To sum up, 76% of the earth pressure is 0.19 ~ 0.22Mpa, 8% of the earth pressure is greater than 0.22Mpa and 16% of the earth pressure is less than 0.19Mpa. The tunnel surface settlement is; the maximum surface settlement is in mileage of ZDK9 895 and ZDK9 905 being -32mm, and the minimum, in mileage of ZDK10 010 being -7.3mm, where the surface settlement greater than -30mm is 20%, less than -20mm, 30%, and -20 ~-30mm, 50%. This can be attributed to the short distance between the lines from left to right of the tunnel, the left line beneath the Binhai Road has disturbed (no residual) soil and the right line adjoins the BinHai Road overpass which has some boulders produced in the sea-filling on top of the tunnel these boulders are relatively large diameter influencing the loading pattern coupled with the long-term cycle of vehicle dynamic loads which have produced cumulative permanent deformation on the road. Though, the overall settlement control is good.

3.2. Stratum Displacement Law of Control Subsystem of Stratum Displacement in Total Thrust

Shield thrust is the equivalent force required to overcome the resistance from the shield's advancing in tunnelling when considering the safety factor. The total thrust includes four resistances: the friction between the shield shell and the soil (F1), the overall resistance of earth pressure (F2), the resistance between the former of shield and the water pressure (F3), the friction between the shield tail and the segment (F4). Fig. 6 is the comparison between the maximum stratum displacement and intelligent control of the total thrust. It can be seen that in mileage of

ZDK9 895 ~ ZDK10 000, 79% of the total thrust is 1100 ~ 1300T, 75% of the surface settlement is in -20 ~-30mm. In mileage of ZDK10 000 ~ ZDK10 045, 84% of the total thrust is 1100 ~ 1300T with a surface settlement less than-20mm. The maximum total thrust is in mileage of ZDK9 935.65, being 1370T, and the minimum total thrust is in mileage of ZDK9 892.15, being 951T.

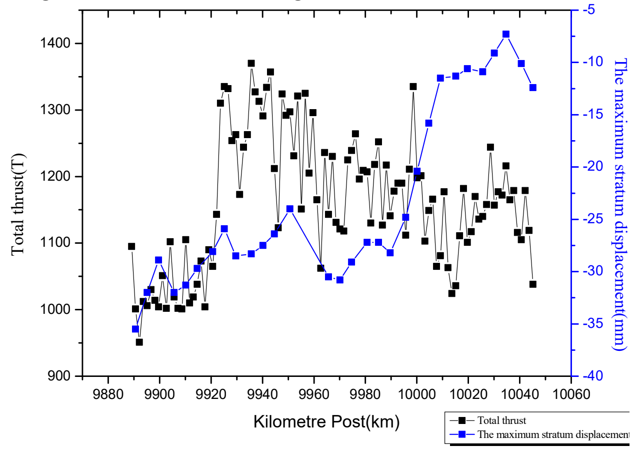

Fig.6. Comparison between the maximum stratum displacement and intelligent control of the total thrust

It is observed that 63% of the total thrust is 1100 ~ 1300T, 11% of the total thrust is greater than 1300T and 26% is less than 1100T. This is mainly because the strata are the gravel (sand) clay with low stability. To construct the shield smoothly, it is necessary to overcome the resistance on the excavation in front of the cutter for soil, and its friction on the surface. Thus, soil properties have great impacts on the resistance and the change of the earth pressure also has an impact on it. The two parameters change "dynamically".

3.3. Stratum displacement law of Control Subsystem of Stratum Displacement in driving

It can be seen that in mileage of ZDK9 895 ~ ZDK10 000, 81% of the shield speed is 38 ~ 48 mm / min, 75% of the surface settlement is -20 ~-30mm. In mileage of ZDK10 000 ~ ZDK10 045, 90% of the shield speed is 38 ~48 mm/min with a surface settlement less than-20mm. The maximum shield speed is in mileage of ZDK9+902.65 being 54.58 mm/min, and the minimum; in mileage of ZDK9+953.65 being 27.7 mm/min, where the shield speed is greater than 48 mm/min settlement is 9%, less than 38 mm/min, 14%, and 38~48 mm/min, 77%. Fig.7. Comparison between the maximum stratum displacement and intelligent control of shield tunneling speed

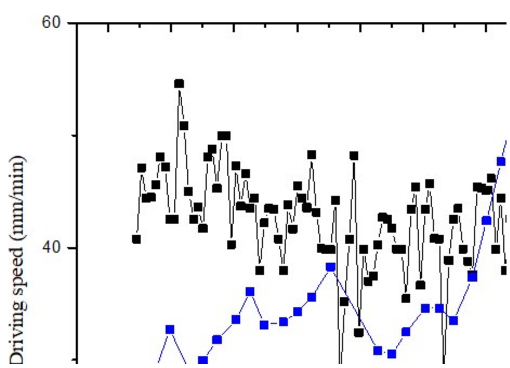

Fig.7. Comparison between the maximum stratum displacement and intelligent control of shield tunneling speed

This is mainly because the shield tunneling balances by discharging the soil. The amount of soil in shield must be equal to the amount of that discharged in the shield. If the shield is too fast, the soil of the shield capsule cannot be discharged, causing the earth pressure-setting out of control. If the advancing speed in the shield is too large and the amount of excavation is small, the front earth pressure will increase, and cause reverse pressure to the soil of the excavation face in the shield. The excavation area of the stratum displacement on the front face of the excavation will be displaced from the direction of the shield which will result in surface uplift. On the contrary, if the advancing speed in the shield is too small and the amount of excavation is too large, it will reduce the soil pressure and move it along the direction with the shield, causing the surface settlement. Notably changes in the groundwater level will affect the operation.

3.4 Stratum Displacement Law of Control Subsystem of Stratum Displacement in Cutter Torque

Cutter torque of the shield includes cutter cutting torque (T1), bearing torque of the cutter weight (T2), bearing torque of the cutter axial load (T3), seal friction torque (T4), friction torque of the front surface in cutter (T5), the anti-friction torque of circumferential surface in cutter (T6). Fig. 8 is the comparison between the maximum stratum displacement and intelligent control of cutter torque. It can be seen that in mileage of ZDK9 895 ~ ZDK10 000, 79% of the cutter torque is 1600 ~ 2300 KN • m, and 75% of the surface settlement is -20 ~-30mm. In mileage of ZDK10 000 ~ ZDK10 045, 50% of the cutter torque is 1600 ~ 2300 KN • m, and the surface settlement is less than -20mm. The maximum torque of the cutter is in mileage of ZDK10 034.65 being 2680KN • m, and the minimum, in mileage of ZDK9 986.65 being 1178 KN • m. In a word, 60% of the cutter torque is in 1600 ~ 2300 KN • m, 22% greater than 2300 KN • m, and 18% less than 1600 KN • m.

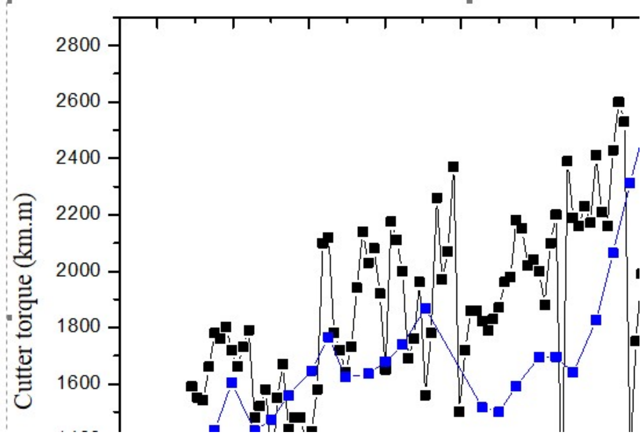

Fig.8. Comparison between the maximum stratum displacement and intelligent control of cutter torque

This is mainly because of the impact of the stress level in the cutter, tunnel depth, and soil features. If the cutter torque is too high, and the thrust is too large when the shield passes through a large number of clay formations, mud cakes may appear in the cutter and the soil cabin because of the permeability is generally low; then the soil cabin will be difficult to open for changing the cutter which will cause the shield in a long-time standstill and stratum displacement further.

3.5. Stratum displacement law of control subsystem of stratum displacement in grouting pressure and grouting volume

Figure 9 and Figure 10 are the comparison between the maximum stratum displacement and intelligent control of grouting pressure and grouting volume. It can be seen that the grouting pressure and grouting volume has great similarity, and reflects the intelligent control process accurately and authentically in shield tunnelling. In mileage of ZDK9 895 ~ ZDK10 000, 79% of the grouting pressure is 0.19 ~0.23Mpa, 81% of the grouting volume is 6.3 ~ 6.8 m^3 and 75% of the surface settlement is -20 ~-30mm. In mileage of ZDK10 000 ~ ZDK10 045, 50% of the grouting pressure is 0.19 ~ 0.23Mpa, 97% of the grouting volume is 6.3 ~ 6.8 m^3 and the surface settlement is less than -20mm.

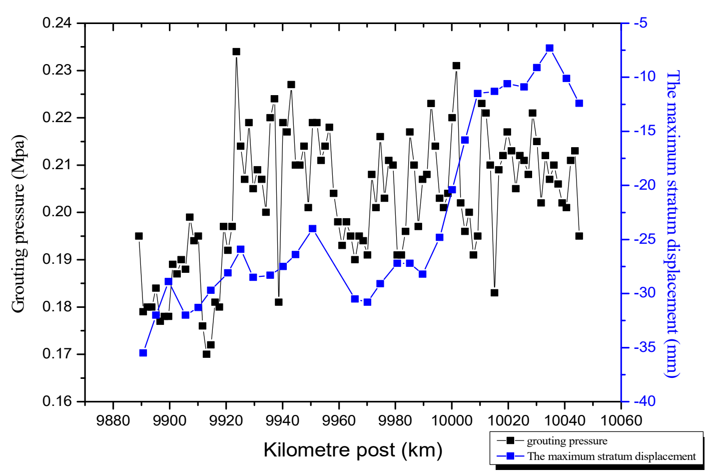

Fig.9. Comparison between the maximum stratum displacement and intelligent control of grouting pressure

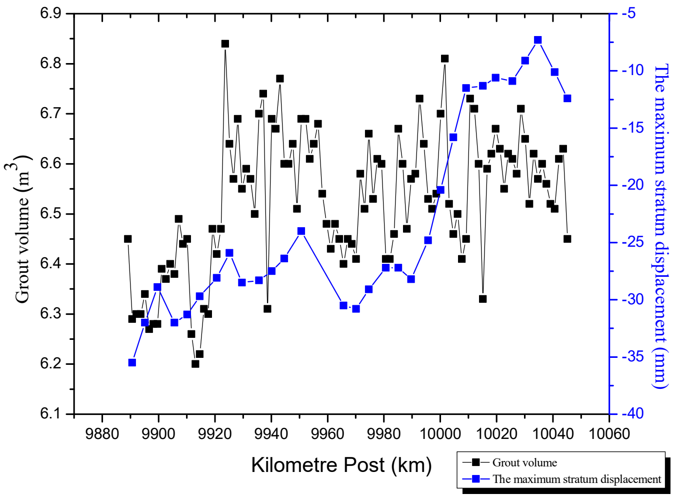

Fig.10. Comparison between the maximum stratum displacement and intelligent control of grouting volume

In a word, the maximum grouting pressure is in mileage of ZDK9 923.65 being 0.234Mpa, and the minimum is in mileage of ZDK9 913.15 being 0.170Mpa. 82% of the grouting pressure is 0.19 ~ 0.23Mpa, 2% of the grouting pressure is greater than 0.253Mpa, and 16% of the grouting pressure is less than 0.19 Mpa.

The maximum grouting volume is in mileage of ZDK9 923.65 being 6.84m^3, and the minimum is in mileage of ZDK9 913.15 being 6.2m^3. 91% of the grouting volume is 6.3~6.8 m^3, 7% of the grouting volume is greater than the 6.8 m^3, and 2% of the grouting volume is less than 6.3m^3. That stratum displacement shows regular features is mainly because of the surface settlement or uplift induced by the shield through the tail gap. When the shield tail falls off, there is a gap between the shield and soil. If, after falling off, the shield is not promptly filled or without sufficient grouting or enough pressure, it will lead to the inward narrowing of hollow section, causing soil stress release. The longer the interval of backfill of grouting is, the higher the soil stress release will be, which causes greater movement of the soil and greater surface settlement. When the grouting is prompt, the soil will move inward towards the tunnel centre, and slowly decreases, then ground deformation will gradually decrease, which will reduce the total surface settlement. Conversely, if there is excessive grouting or pressure, the deformation of the segment will increase, resulting in surface uplift.

4. Stratum Displacement Intelligent Optimization Control

Stratum displacement intelligent optimization control makes an intelligent analysis of the monitoring data of deformation in soil and structures during the shield tunnelling using the model of intelligent fuzzy control theory established in this paper. Basing on the comprehensive judgements of pre-shield, it gives instant feedback of the analysis and promptly optimizes the parameters set up during the shield tunneling, including earth pressure, total thrust, driving speed, cutter torque, grouting pressure and grouting volume to predict the possible new circumstances in the follow-up cycle and further optimize the various parameters, which achieves the intelligent control of shield tunneling and gives guidance to safe excavation for follow-up shield, and further eliminates a variety of possible dangerous situations.

4.1. Earth pressure

Earth pressure setting is directly related to the surface settlement. Combining Fig. 5, it can be known that when the setting of earth pressure is greater than 0.22Mpa, the surface will cause devastating damage and lead to greater surface settlement; when the setting of earth pressure is smaller than 0.19Mpa, it will lead to larger surface settlement in front of the excavation and greater total settlement. Thus, the earth pressure setting should be controlled between 0.19 ~ 0.22Mpa, which means the best control objective is that the soil in front of excavation produces a small amount of settlement.

4.2. Total thrust

The force of the thrust directly reflects the degree of movement on the excavation surface and the soil around the tunnel, which is one of the main factors for surface settlement. Combining with the analysis of Fig. 6, it can be known that when the total thrust is greater than 1350T, the surface in front of the excavation will be uplift, and eventually lead to surface settlement; when the total thrust is less than 1100T, the surface in front of the excavation will lead to a settlement. Thus, during the shield tunnelling, the force of thrust and the movement of the soil is of a direct relationship, and the best total thrust should be controlled at 1100 ~ 1350T to ensure the security of the shield machine and construction procedure.

4.3. Driving speed

Driving speed is related to earth pressure, jack thrust, soil properties, shield machine type and so on. The speed of shield advancing has direct impacts on the settlement of Binhai Road. Combining the analysis of Fig. 7, it can be known that when the driving speed is greater than 50mm/min, the surface in front of the excavation will be uplift, and eventually lead to surface settlement; when the driving speed is less than 38mm/min, the cutter speed slows down and will lead to settlement in front of the tunnel. Thus, the driving speed should be controlled at 38 ~ 50mm/min, which means time control is roughly between 30 ~ 40min for each tunnelling part (1.5m), and advancing speed should be constant for the best performance. for reducing the movement of excavation in soil.

4.4. Cutter torque

Combining with the analysis of Figure 8, it can be seen that when the cutter torque is 1600 ~ 2300 KN • m, it will help to control surface settlement; when the cutter torque is greater than 2300 KN • m, it will easily lead to tool wear and the formation of mud cake, resulting in surface settlement; when the cutter torque is less than 1600 KN • m, it will easily lead to damage of the shield cutter, bearings and other components, resulting in greater economic losses. Thus determining a reasonable torque on the shield cutter is extremely important in shield tunnelling.

5. Grouting Pressure And Grouting Volume

Grouting pressure and grouting volume are directly related to the segment leakage and the settlement. Combining with the analysis of Figure 9 and Figure 10 below. It can be seen that, grouting pressure and grouting volume has a clear positive relationship. If the grouting pressure is greater than 0.25Mpa and the grouting volume is greater than 7.2m3, the surface in front of the excavation will be uplift, and eventually lead to surface settlement; if the grouting pressure is less than 0.19Mpa and the grouting volume is less than 6m3, it will lead to the gap's due to lack of filling after the segment falls off the shield tail, resulting in the settlement. Therefore, when the grouting pressure is 0.19 ~ 0.25Mpa and the grouting volume is 6 ~ 7.2 m3, ground deformation can be controlled to the minimum and improve the tunnel's water tightness; meanwhile, it can ensure the early stability of the segment lining, ensure the uniformity of the external force on the segment, and prevent segment from floating, shifting or mismatching.

6. Conclusions

This paper introduces the intelligent fuzzy control theory, combining with the analysis of stratum displacement laws and intelligent optimization control of HouHai-KeYuan shield section of Shenzhen Metro Line 2 beneath Tianma River Binhai Road. The main conclusions are as follows:

(1) Selecting earth pressure, total thrust, driving speed, cutter torque, grouting pressure and grouting volume and other factors as the main objects of the study, and combining the input and output of the control target of the five stages of the surface settlement caused by shield construction, together with the design of fuzzy controller, a theoretical model of intelligent fuzzy control is established.

(2) A system with five two-dimensional structures and a double structure of fuzzy control is constructed. These subsystems are control subsystem of stratum displacement in earth pressure, control subsystem of stratum displacement in total thrust, control subsystem of stratum displacement in driving speed, control subsystem of stratum displacement in cutter torque, and control subsystem of stratum displacement in grouting pressure and grouting volume.

(3) Stratum displacement laws for the earth pressure, the total thrust, the driving speed and other five control subsystem of stratum displacement are analyzed, based on the model of intelligent fuzzy control theory. The paper holds that the model is of current and available instantaneity and availability, and the control of each parameter develops stably in shield tunnelling.

(4) Based on the model of intelligent fuzzy control theory, the paper defines the optimal control theory for stratum displacement and optimizes the intelligent optimization control of the parameters in shield tunnelling, which recommends that;The parameter ranges should be controlled as follows: earth pressure, 0.19 ~ 0.22Mpa; total thrust, 1100 ~ 1350T; driving speed, 38 ~ 50mm / min; cutter torque, 1600 ~ 2300 KN • m; grouting pressure, 0.19 ~ 0.25Mpa and grouting volume, 30 ~ 50L/min. . These figures have significant implications on the safety, cost, quality and of the tunneling process as observed.

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