（様式２）

氏　　名　：馬 鵬

論 文 名　：DESIGN OF EXCAVATION MACHINE AND JACKING PIPE, AND ESTABLISHMENT OF JACKING FORCE PREDICTION EQUATION FOR RECTANGULAR PIPE JACKING METHOD（矩形推進工法における掘進機と推進管の設計および推進力算定式の構築に関する研究）

区　　分　：甲

論 文 内 容 の 要 旨

The underground infrastructures such as subways, sewage systems, power supply systems, and utility tunnels now are in need of more environmentally friendly and sustainable construction. However, it is difficult to apply the conventional open-cut method to construction on underground space in urban areas due to various political and ecological restrictions. The pipe jacking method which is a trenchless technology, which has advantages of low comprehensive cost, no disturbance to the traffic order, and a low environmental impact, has been widely used in North America, European countries, and in East Asian countries. Nowadays, a refined application of underground space has become a new trend for all metropolises as a rectangular space has a higher space utilization ratio compared with a circular space. Therefore, rectangular pipe jacking technology now has more potential application scenarios. Based on the above-mentioned backgrounds, the purpose of this research is to develop a new rectangular pipe jacking technology especially for designs of an excavation machine and a jacking pipe, and to establish an accurate jacking force prediction equation for a rectangular pipe jacking which considers the pipe-soil contact state. Thus, this research mainly focuses on the key technical points of the rectangular pipe jacking method and the main contents in each chapter are listed as follows:

Chapter 1: Trenchless technology and the existing underground space construction methods are introduced and compared in this chapter. The technology history, technical connotation, and the operating procedures of rectangular pipe jacking are described. Moreover, the existing theoretical solutions for estimating face stability and jacking forces are investigated. Meanwhile, the research background, motivation, and main purposes of this research are described.

Chapter 2: As to understand the current situation and the key issues for rectangular pipe jacking technology, a series of technical investigations and analyses are carried out in this chapter. The issues related to excavation-face instability, interference of excavation procedures, mechanical restrictions of rectangular excavation machine, and the corresponding countermeasures are discussed. In this chapter, the existing rectangular excavation mechanisms are compared, including the parallel shaft type, duplex type, and modular type. The function upgrades for a new rectangular excavating machine need to be considered in terms of technical applicability and the market. Moreover, the four new emerging application scenarios for rectangular pipe jacking are summarized.

Chapter 3: The geometry configurations of jacked rectangular pipe need to be examined before construction. The critical issues related to the jacked pipe geometry include three aspects: (i) the induced ground response; (ii) the jacking forces and operation adaptability; and (iii) stress distribution characteristics and load-bearing performance with different geometric parameters. Therefore, the ground response characteristics under four rectangular pipe aspect ratios with the same utilization cross-section area are investigated by using the finite element method with 3D-σ software as a series of case studies. It was found that the vertical displacement of the ground surface decreases with the increase of aspect ratio and the ground surface deformation is more sensitive to the change of the width of a jacked rectangular pipe. Moreover, the surface horizontal displacement also decreases with increasing the aspect ratio. The vertical displacement of the ground surface decreases with increasing buried depth. In terms of the jacking force, it increases as the aspect ratio increases under the same buried depth. It can be considered that the lubricant material filled between pipe and soil and face pressure may not work effectively when the aspect ratio of a rectangular pipe increases. Finally, the effect of the aspect ratio on the mechanical performance of a pipe slab is simulated.

Chapter 4: In this chapter, an innovative stepped rectangular pipe jacking machine is proposed for the first time to enhance the capacity of the rectangular excavation machine to deal with the new emerging complicated application conditions. With the stepped excavation system, the large tunneling face can be divided into multiple stepped small faces to improve the soil stability of the whole tunnel face, which could create more favorable conditions for a large excavation face in complicated conditions and control the subsidence of ground surface. Based on the limit equilibrium method, an improved three-dimensional wedge-prism model is proposed to investigate the effectiveness of the stepped excavation system and its design guideline. In this model, the limit pressure on each step face is taken as an index to evaluate the performance of different design schemes. It is found that an upper face height of around 1/3D for the whole tunnel height, D can achieve better face stability under different scenarios. The appropriate step width in this analysis is between 0.1D to 0.2D. Meanwhile, the stability of the excavation face and the settlement mechanism of the ground surface of the proposed rectangular pipe jacking machine are discussed by means of the finite element method. It can clearly be seen that a stepped excavation face can reduce ground deformation. Besides, considering the different face support schemes, the proper face support pressure in the upper and lower faces should be between the active earth pressure and static earth pressure.

Chapter 5: In this chapter, a new friction force prediction equation is proposed for rectangular pipe jacking. There is no prediction equation for rectangular pipe jacking thus far. If the prediction equations based on the circular design are adopted for rectangular pipe jacking, the final results are always overestimated. From this background, the prediction equation is established considering the mechanism of the surrounding soil. In order to implement this phenomenon for friction force prediction, the pipe-soil contact ratio λ, which is defined to evaluate the pipe-soil contact state, is introduced to a new friction force prediction equation. Here, $\lambda=0$ indicates that the void between pipe and soil in the sidewall is filled with lubricant material exactly and $\lambda=1$ indicates that the void between pipe and soil in the sidewall is fully replaced the lubrication material with soil. The contact interface resistance between the slurry and the pipe sidewalls is considered as well. Simultaneously, the normal contact pressure on the roof slab is calculated based on the arching effect. The pipe weight and pressure from the roof are considered for the bottom slab. Compared with field data which is on a long-distance jacking construction and the cross-section is a rectangular shape with an aspect ratio of 0.5, it can be verified that the jacking force can be predicted with an error of about 2.5% by applying this new friction force prediction equation. The actual sidewall friction increases with increasing the aspect ratio and this result is consistent with Chapter 3. It can be concluded that the proposed friction force prediction equation considering the pipe-soil contact state can be verified and applicable for prediction jacking force for the rectangular pipe lacking construction.

Chapter 6: This chapter concludes the results of this research.