Research on the Geotechnical Engineering Investigation and Foundation Treatment Methods of Large Thickness Collapsible Loess

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Abstract. Geotechnical engineering plays a valuable and fundamental role in the process of engineering construction in China, and during the process of geotechnical engineering construction, engineering investigation and foundation treatment have significant influence on the whole construction quality of the geotechnical engineering. The widespread distribution and overall features of collapsible loess bring more difficulty for engineering investigation and foundation treatment. Any failure of accurate investigation and effective foundation treatment may lead to the collapse during the engineering construction. There is a large area of collapsible loess in the northwest of China, especially in Lanzhou, and such extensive distribution of collapsible loess makes it quite difficult during the geotechnical engineering construction. How to conduct effective geotechnical engineering investigation and foundation treatment for collapsible loess is the priority of researches on geotechnical engineering construction in Lanzhou for the moment. During the process of foundation treatment of collapsible loess, the overall characteristics of loess should be taken into consideration, and then it shall be analyzed and demonstrated from perspectives of economy, rationality and feasibility. This paper takes Lanzhou as the research object and carries out the research on the geotechnical engineering investigation and foundation treatment methods in this area during the research process. The research outcomes can serve as empirical support and theoretical reference for geotechnical engineering investigation and foundation treatment of large thickness collapsible loess, and further improve the construction quality and economic benefits of geotechnical engineering.

1. Introduction
The large thickness collapsible loess, widely distributed in China, will rapidly decomposed when soaked under certain pressure, and then sink significantly and extra, thus leading to the severe collapse deformation of building’s foundations. Therefore, it’s quite difficult to carry out geotechnical engineering construction under such geological conditions. For geotechnical engineering construction on the large thickness collapsible loess, it’s necessary to conduct effective investigation on the geological environmental conditions of sites full of collapsible loess, and carryout special treatment on the foundations of such sites. Otherwise, the inundation deformation of foundations with collapsible loess, during the construction or operation of geotechnical engineering, will severely impair the constructional engineering, as well as materially jeopardize the integral security and functionality of buildings. The collapsible loess is distributed in broad region of China, such as Gansu region, Ningxia region, Shaanxi region, Shanxi region and western region of Henan. Its total area in China accounts for more than 4% of the world’s total area of loess, and its total area of continuously distributed loess
is up to 4.45×105km2, with the overall thickness of loess being 15-405m. Chinese government has been attaching importance to the development and infrastructure construction of western regions. Therefore, during the development and infrastructure construction, it’s necessary to conduct effective engineering investigation and foundation treatment of collapsible loess, find out the thickness, lowest depth, collapsibility type and collapsibility grade of loess, and propose foundation treatment schemes suitable for local geological conditions to further ensure the construction quality of geotechnical engineering and serve China's economic and social development in a better way.

2. Distribution and Engineering Features of Large Thickness Collapsible Loess in Lanzhou Region

2.1 Features of large thickness collapsible loess foundation
The large thickness collapsible loess foundation generally refers to the collapsible loess foundation with the lowest depth of collapsible loess over 20m under the foundation at the self-weight collapsible loess sites, under which conditions, general engineering investigation and foundation treatment methods cannot meet the needs of the construction of large thickness collapsible loess sites. The large thickness collapsible loess is widely distributed in Gansu, Shaanxi, Shanxi and other regions, and these regions are featured with special weather conditions, such as rare rain capacity, strong evaporation and deep underground water level, all of which will impose considerable impact on engineering construction. The large thickness collapsible loess is featured with relatively large thickness, relatively low water content in the foundation soil, and relatively high collapsibility. The degree and type of large thickness collapsible loess are largely affected by the surroundings of sites and directly related to the life and production of human beings. For those regions with less human activities, the collapsibility type and foundation collapsibility of large thickness collapsible loess do not change much, remaining strong regularity, while at the regions with more human activities, under the influence of agriculture and afforestation irrigation, the collapsibility of sites will change markedly, the relevant engineering investigation indicators will fluctuate widely, and the distribution regularity of large thickness collapsible loess will get weakened.

2.2 Engineering situation and distribution of large thickness collapsible loess in Lanzhou
Lanzhou city is an important city in Northwest China, and the urbanization development level in Lanzhou city has been constantly improved, urban construction works have been speeding up. The engineering construction in Lanzhou region has been gradually expanding towards Gaolan Mountain, Xujia Mountain, Wuyi Mountain, Baita Mountain, Jiuzhoutai and other land development areas in North-South mountains, as well as the satellite towns in the urban periphery of Yuzhong and Gaolan districts. At the sites newly expanded in the process of urban construction, there is extensively distributed large thickness collapsible loess, with the overall thickness being 25-45m, which is classified into severe self-weight collapsible loess. In this way, it is rather difficult during the geotechnical engineering construction. Considering the relatively major technological difficulties caused by the large thickness collapsible loess to the geotechnical engineering construction, it is necessary to accurately find out the engineering geological conditions during the process of engineering construction and conduct effective treatment on the foundation. How to select reasonable and economical investigation schemes and foundation treatment technologies during the construction is a challenge faced by relevant technical staff. The construction personnel shall make a comprehensive evaluation of the engineering features of the foundation soil before the construction of the project, so as to ensure the selection of economical and reasonable foundation forms and foundation treatment methods in the construction process, which is the primary technical problem needed to be solved by the investigation technical staff.
2.3 Site engineering geological conditions in Lanzhou region

2.3.1 Climate conditions
Lanzhou region has a temperate semiarid climate and distinct continental climate characteristics. The geotechnical engineering construction site is featured with abundant sunlight, dry climate, rare rainfall and strong evaporation. The mean annual precipitation in this region is 338.6mm, and the precipitation mainly happens from July to September in the form of rainstorms. The annual evaporation in this region is 1,438.8mm, and no underground water emerges within the general investigation depth. According to the hydrological and geological data at the engineering construction sites, this region is at the Quaternary strata, without underground water contained, and the buried depth of underground water is more than 50m.

2.3.2 Geological conditions
The local geological conditions can be described and evaluated from the following zones, respectively, Yuzhong Heping Development Zone, Fanjiaping on the south bank of the Yellow River, Baidaoping on the north bank of the Yellow River, and Dashagou Land Development Zone. All these zones are featured with distinct geological conditions, wherein, the loess in Yuzhong Heping Development Zone is flood alluvial loess, with the overall thickness being 26-46m, the overall thickness of collapsible loess being 8-26m, and relatively large overall amplitude of variation. The under layer of flood alluvial loess is breccia interbeds with silty clay or silty soil. The loess overs on the Tertiary Cretaceous purplish red sandstone and conglomerate, leaving the overall construction site being relatively smooth. The large thickness collapsible loess at Fanjiaping on the south bank of the Yellow River, Baidaoping on the north bank of the Yellow River was formed in an earlier period, with flat and open terrace surface, continuous distribution, large area and erosion slicing only developed between Fanjiaping and Baidaoping. These zones were used to be dry farmland, and have gradually developed to be fruit and vegetable bases and green land after lifting and pumping water from the Yellow River. The loess type in this zone is eolian loess-like silt, with the overall thickness being 26-32m, and the thickness of collapsible loess being 8-28m. The original landform at Dashagou Land Development zone is loess gullies and hills, and now has developed to be engineering construction site after backfilling, excavation, reclamation and leveling. The loess in this zone, being 6-26m thick, is featured with strong collapsibility and high compressibility, and it mainly consists of silt as well as a small amount of sandstone fragments.

2.4 Engineering features of collapsible loess in Lanzhou region
After investigation, the collapsible loess in Lanzhou region possesses following features: first of all, the large thickness collapsible loess has larger soil natural density and high coefficient of compressibility, with the void ratio decreasing along with the increase of loess depth, and the overall water content and saturability of loess decreasing along with the increase of loess depth. However, there is no distinct correlation and overall trend. For the changes of coefficient of compressibility and dry density along with the increase of loess depth, please refer to Figure 1 and Figure 2.
Second, the large thickness collapsible loess is featured with collapsibility within 30-35m, which will impose more influence on engineering construction. The collapsibility seems to get weak along the increase of loess depth, namely, the collapsibility of foundation soil within 0-10m being stronger, within 10-20m being medium, and within 25-30m being weak, for the changes of coefficient of collapsibility and coefficient of self-weight collapsibility along with the increase of loess depth, please refer to Figure 3 and Figure 4.
Figure 3. Scatter Diagram of the Changes of Coefficient of Collapsibility along with the Increase of Loess Depth

Figure 4. Scatter Diagram of the Changes of Coefficient of Self-Weight Collapsibility along with the Increase of Loess Depth

3. Problems in the Geotechnical Engineering at the Large Thickness Collapsible Loess Sites of Lanzhou Region

3.1 Problems in the depth of investigation of Lanzhou region
Investigating the depth of large thickness collapsible loess is an important basis of engineering investigation, as well as foundation treatment. According to Code for Building Construction in Collapsible Loess Regions, there should be certain amount of soil-sampling exploratory points cutting through the collapsible loess layer during the geotechnical engineering investigation, but there is no strict rule on penetration of the collapsible loess in the relevant regulations and practical operations.
During the investigation, many investigation staff takes 15m as the largest depth of sampling. This depth is in line with the relevant standards, but fails to conduct effective investigation on the depth of collapsible loess, which makes it impossible to conduct comprehensive recognition on the distribution features of collapsible loess, or carry out design and foundation treatment.

3.2 Problems of collapsibility test pressure in Lanzhou region

In the Code for Building Construction in Collapsible Loess Regions (GB50025-2018), there are explicit provisions on the test pressure measuring the coefficient of collapsibility. The saturated dead weight pressure of overlying soil should be applicable to 10m beneath the foundation to the top of non-collapsible loess layer; when the foundation pressure is more than 300KPa, the actual foundation pressure should be applicable, while when the saturated dead weight pressure of overlying soil is more than the actual foundation pressure, the saturated dead weight pressure of overlying soil should be applicable. However, many investigation staff fails to conduct measurement in strict accordance with Code GB50025-2018 in the process of investigation, or fail to calculate the saturated dead weight pressure at different depth according to the different dry density and saturability. The inaccurate or lax pressure selected for test pressure in the tests may lead to great differences between test results and actual conditions.

3.3 Problems in the evaluation of collapsibility degree in Lanzhou region

The evaluation on the collapsibility of large thickness loess plays the fundamental reference for foundation treatment and engineering investigation, and it is necessary to conduct classification and evaluation on the collapsibility type of sites and collapsibility degree of foundation soil according to the provisions of standards during the process of classifying the collapsibility degree. Conducting evaluation on the collapsibility of loess according to the corresponding standards is of great significance, and there should be differences between recognition and treatment. Treatment on the large thickness loess foundation should be proceeded respectively by classifying the collapsibility degree as specified in the standards, and it is critical to the recognition of collapsibility at different engineering sites and different kinds of engineering design and foundation treatment. During the engineering foundation treatment and construction, it is necessary to conduct effective investigation on geotechnical engineering by strictly following the engineering construction system, and then carry out the foundation treatment. Further investigation should be proceeded on regions with better stability and less treatment work quantity during the engineering construction.

4. Foundation Treatment Methods for Geotechnical Engineering with Large Thickness Collapsible Loess in Lanzhou Regions

4.1 General idea and procedures of foundation treatment

During the process of foundation treatment, it is necessary to conduct engineering geological investigation on local geological conditions, and foundation treatment on collapsible loess should be generally conducted by applying the deep-in-hole dynamic compaction method of compaction methods, which can achieve excellent effects in the process of treatment. During the process of foundation treatment, high dynamic olivary hammer should be adopted for dynamic compaction. This method is featured with unique and remarkable advantages. When proceeding foundation treatment, theodolite will be used to determine the control points and pile positions, then pore-forming works should be carried out, and finally artificial packing should be implemented by applying the lime-soil mixer to screen and mix. Outstanding outcomes will be achieved by applying this method in the foundation treatment, and deep-in-hole dynamic compaction method can significantly improve the overall quality of foundation treatment. Foundation with large thickness collapsible loess should be handled separately according to the requirements.
4.2 Methods to control residual collapse settlement in the foundation treatment
During the process of settling the large thickness collapsible loess, it is necessary to carry out effective control on the residual collapse settlement, and construction should be carried out in strict accordance with relevant engineering regulations and local construction conditions. Even for Class C buildings at the self-weight collapsible loess sites, its treatment thickness should be no less than 10m, and the residual collapse settlement that untreated collapsible loess layer in the lower part should be no more than 300mm. It is quite difficult for general foundation treatment methods to play roles in treating large thickness collapsible loess. In addition to pre-soaking and other a few treatment methods, it is impossible to find other treatment methods that can meet the residual collapse settlement requirements within short construction duration at low cost.

4.3 Foundation treatment methods for loess sites with the collapse thickness over 20m
For large thickness collapsible loess sites with the collapse thickness over 20m, if the residual collapse settlement is less than 300mm, pre-soaking method should be applied as priority to carry out the foundation treatment during the process of foundation treatment. The application of pre-soaking method for foundation treatment will significantly change and improve the soil collapsibility and other physical mechanical property indexes, speed up the foundation treatment and complete within a short construction duration. At the meanwhile, this method is featured with relatively low overall cost, and can meet the requirements on residual collapse settlement. For collapse deformation of the site ground caused by low water content and incomplete compaction at the large thickness collapsible loess construction site, it is necessary to consolidate the slopes at the periphery of projects.

Large thickness loess foundation can also be processed by applying combined methods. For example, apply the pre-soaking method to eliminate the collapsibility of deep loess, and adopt the cushion method, compaction method or dynamic compaction method to handle the loess on the superficial layer; or apply the pre-soaking method to eliminate the collapsibility of deep loess, and then adopt the rigid-pile composite foundation or pile foundation. In such way, the negative friction resistance of plies in the soil layers with collapsibility eliminated will no longer be calculated, and soil-between-piles bearing capacity and friction resistance will both substantially improved, combined with the water-proof function, this method shall prevail in both technology and economy.

4.4 Drainage measures in the foundation treatment process
Special attention should be paid to the construction of drainage facilities during the process of foundation treatment. Drainage facilities should be designed according to the actual conditions of the site. Meanwhile, it is necessary to design and construct the water-proof function and leakage detection function on heating system, water supply and drainage system, vent pipes and ditches, which shall be under the conditions without eliminating the collapsibility treatment on the site and foundation soil. According to several engineering accidents occurred in high-level terraces and Jiuzhou Land Development Zone in Lanzhou city, for buildings on the large thickness serous collapsibility loess and filling fields, missing to carry out surface treatment on the site and foundation soil after ensuring the safety of buildings by applying pile foundation to penetrate the collapsible loess layer or fill stratum, will often lead to setting of pipe ditches, terrace and equipment foundation, especially at the backfilling fields with incomplete self-dead compaction and consolidation.

5. Conclusion:
In conclusion, this paper mainly studies the investigation and foundation treatment methods of geotechnical engineering with large thickness collapsible loess during the research. The large thickness collapsible loess is extensively distributed in China, especially in Lanzhou region. According to the research outcomes of this paper, the engineering site with large thickness loess in Lanzhou region is featured with strong collapsibility, and the collapsibility will get weak along with the increase of the depth. This kind of collapsibility belongs to self-weight collapsibility, with high collapsibility degree. Since such loess is mainly located at the loess ridge areas, there are slopes,
penetrating caves and other environmental geotechnical engineering problems. During the process of engineering investigation, investigation shall be carried out according to the collapsibility degree of large thickness collapsible loess and engineering construction features. During the process of engineering foundation treatment and construction, it is necessary to proceed effective investigation on projects in strict accordance with engineering construction system, and then carry out the foundation treatment. Meanwhile, for collapse deformation of the site ground caused by low water content and incomplete compaction at the large thickness collapsible loess construction site, it is necessary to consolidate the slopes at the periphery of projects. This measure can further improve the long-term stability of sites, prevent the occurrence of collapse and other problems that can affect engineering safety during the construction and operations after completion, and further boost the construction quality and economic benefits.

References
[1] Yang.X.J(2019).Geotechnical investigation and comparative analysis of foundation treatment of a collapsible loess site with large thickness.J.Building Materials and Decoration.2019(32):238-239.
[2] Lu.L(2019).Foundation treatment and foundation selection after excavation and reconstruction of a collapsible loess site with large thickness.J.Gansu science and technology.35(01):78-80.
[3] Luo.Y,Lin.Y(2018)Geotechnical investigation and foundation treatment of collapsible loess with large thickness.J.Engineering research.(14):232-233.
[4] Wang.J.H(2016)Site investigation of collapsible loess with large thickness and comprehensive prevention measures.J.Shanxi building.42(19):60-61.
[5] Wang.X.L(2012)Study on collapsible deformation mechanism, foundation treatment and experimental study of large - thickness collapsible loess.D.Lanzhou University of Technology.