Discussion of Some New Trends in Mechanics and Engineering Research of Collapsible Loess

PingLi¹*, YunxiuDong¹, LipingLiu¹

¹Department of civil engineering, Long Dong University, Qing Yang, Gan Su, 745000, China
* e-mail: 253679058@qq.com

Abstract: A brief introduction is provided on the overall trend of the global-wide research on loess distribution in China and the collapsible reasons of collapsible loess. Recent achievements are discussed as well as basic properties and engineering research status of collapsible loess. The future some new research direction is also presented.

1. Introduction

Loess covers an area of 1300 square kilometers in the vast territory of China, mainly distributed from east to west in the northwest dry inland basin, the central loess plateau, the eastern piedmont hills and plains, and so on. In the loess widely distributed within the unique structural, obvious regional expansive soil and red clay, permafrost, saline soil, collapsible loess, such as special soil type, the soil type is sensitive to moisture migration, changes in temperature is not stable, and the inconsistency between the mechanical and physical properties are, and these characteristics can induce the change of the soil mechanics properties, belong to the bad geological phenomenon, needs to take effective treatment measures to prevent the happening of the engineering disasters. For a long time, scholars at home and abroad have carried out fruitful research on engineering characteristics, theoretical models and testing techniques of various special soils. It can be said that the development of the theory and technology of special soil is an important field of geotechnical research at home and abroad [1].

The collapsibility of loess is mainly under the action of dead weight stress of overlying soil layer, or under the action of dead weight stress and additional stress, the structure failure produces a large number of rapid subsidence, which causes serious harm to engineering construction. Collapsible loess, which accounts for about three quarters of the total loess, is mainly distributed in the middle reaches of the Yellow River. This area is located between latitude 34 ~ 41 degrees north and longitude 102 ~ 114 degrees east. It starts from the Great Wall in the north, reaches the Qin Ling mountain in the south, starts from Wu Qiao Ling mountain in the west, and reaches Tai Hang mountains in the east. Apart from the river-gully cutting area and the outstanding mountains, collapsible loess almost covers the whole area of this region, which is a typical area of loess in China. In addition, it is also distributed in central Shandong province, The Hexi corridor of Gansu province, inland basin of northwest China and The Songliao plain of northeast China. The collapsible loess is generally covered in the non-collapsible loess layer, and its thickness is larger in the west of Liupanshan, up to 30 meters. The area east of Liu Liupanshan is slightly thinner, further east to the west of Henan province is smaller, and often the non-collapsible loess lies between the collapsible loess.

Due to the variety of special soils and the wide range of collapsible loess, this paper only briefly discusses some new trends in the mechanics and engineering research of collapsible loess.
2. Collapsibility mechanism of loess

The collapsibility of loess is a complex physical and chemical process, and its causes and mechanisms can be summarized as internal and external causes. The internal cause is mainly due to the material composition (skeleton particles and cementation) and structural characteristics of the soil, while the external cause is the action of water and pressure mechanics.

Collapsible loess formation at the beginning of a small amount of loose powder by seasonal rain stick together, in the long drought environment moisture to evaporate, soluble salt gradually concentrated precipitation formation of cement, thus forming with coarse powder as the main body skeleton of pore structure, the connection between the particles form and arrangement of structural system of the direct impact on the loess cementation strength and the stability of the structure system. At the same time, due to the existence of cementation strength, the stress-strain relationship and strength characteristics of collapsible loess are obviously different from other soils. However, once the soil structure is soaked by water, the chemical and physical action of the internal system leads to the decrease of internal bonding force, strength and rapid destruction, which presents such characteristics as yield, softening and collapse. The soluble salt content not only affects the collapsibility, but also determines the type of collapsibility. [2],[3]. From the mechanical point of view, whether the soil is collapsible or not depends on the interface of the soil. When the stress of the collapsible soil is greater than the shear strength, there will be collapsibility; otherwise, there will be no collapsibility [2], [3].

According to the building code of collapsible loess area of China (GBJ 25-90), the collapsibility coefficient of wet loess is used as the mechanical parameter to evaluate the collapsibility of loess, that is, under certain pressure, the ratio of the difference between the height of soil samples before and after water immersion and the original height of soil samples. The sag coefficient $\delta_s$ is calculated according to the following formula:

\[
\delta_s = \frac{h_p - h_p'}{h_0}
\]

There is: $h_0$ — the original height of the soil sample, m; $h_p$ — the height of the soil sample after compression and stabilization under the action of specified experimental pressure P without lateral expansion, m; $h_p'$ — the soil sample under pressure is soaked to reach the height of the soil sample after the collapsible stability, m.

The collapsible coefficient $\delta_s$ is soil layer of unit thickness. According to the specification, when $\delta_s \geq 0.015$, it shall be deemed as collapsible loess, otherwise it shall be deemed as non-collapsible loess. In addition, the collapsibility of loess is related to the pressure. The minimum pressure of collapsible loess is called the initial pressure of collapsibility. For example, the collapsible loess caused by the dead weight pressure of the overlying soil layer is called dead weight collapsible loess. The collapsible loess is called non-dead weight collapsible loess, which does not collapse under the saturated dead weight pressure after being immersed in water.

Combining the reality of structure and foundation, in order to correctly reflect the collapse degree of collapsible loess strata, using reasonable and effective protective measures, to calculate the collapsibility coefficient of each soil layer in the foundation, obtained by the calculation of foundation collapsibility quantity $\Delta_s$ (m):

\[
\Delta_s = \sum \delta_{si} \cdot h_i
\]

| Calculated subsidence of foundation (m) | Calculated subsidence of foundation |
|----------------------------------------|-----------------------------------|
| $0.05 < \Delta_s \leq 0.15$            | I                                 |
| $0.15 < \Delta_s \leq 0.35$           | II                                |
| $\Delta_s > 0.35$                     | III                               |

Table 1. Grades of collapsible loess foundation
Specification in accordance with the $\Delta_s$ to determine the collapsible loess collapsibility level (table 1), but $\Delta_s$ collapsibility cannot reflect the reality of the foundation, only the qualitative indexes of collapsible loess foundation. Because the collapsibility of the loess upper soil is greater than that of the lower soil, the collapsible soil thickness is generally calculated from the base to 5m below.

In addition, China's building code also stipulates that when the soil layer below the basement contains self-weight collapsible loess, the following formula can be used to determine whether it is self-weight collapsible foundation.

$$\Delta_s = \sum \delta_{zi} \cdot h_i$$

According to a large number of indoor and outdoor test contrast, when $\Delta_s$ acuities were 0.07 m can be as the weight of collapsible loess foundation, $\Delta_s > 0.11$ m as a weight of collapsible loess foundation; $\Delta_s$ is 0.07 ~ 0.11 m, can be combined with local practice experience [4].

3. Some new trends in mechanics and engineering research of collapsible loess

The research on collapsible loess has developed from the initial study on the basic properties and changing laws to the research on the micro-structural characteristics of collapsible loess, the correlation between microstructure and loess structural strength and collapsibility [5]. In recent years, with the increase of the number and scale of loess area construction, the research and understanding of collapsible loess becomes more and more important.

3.1. water transport law of collapsible loess

Permeability is one of the important engineering properties of loess. Many engineering practices have proved that the size and velocity of collapsible loess foundation are closely related to the permeability of loess. Domestic scholars such as YingLiu and NuaoLiu have made some beneficial attempts, but there are few studies on how the water in the unsaturated undisturbed loess penetrates and migrates. XuefengHuang et al. concluded through field tests that the seepage range in unsaturated loess is a closed and approximately elliptic region, and the permeability is mainly reflected in the law of water transport. Up to now, the study on the law of water transport in loess is far from enough, and the report on the law of infiltration is rare. How to design the experiment reasonably? Is the law of water migration related to the depth of treatment? It should be studied in depth.

3.2. treatment depth of collapsible loess foundation with large thickness

With the development of the national economy and the implementation of the western development strategy, industrial and civil projects with large quantities, large scale and long distance need to be built on collapsible loess with large thickness and dead weight. The so-called large thickness refers to the collapsible loess foundation with a thickness of more than 15m and a bottomless depth. The thickness of loess layer affects the dead weight sag and collapsibility caused by saturated dead weight pressure. According to the scope of collapsible deformation, the treatment thickness of the foundation can be divided into two types: the treatment of total collapsible deformation and partial collapsible deformation. The purpose of the former is to eliminate all the collapsibility of the building foundation, while the latter only eliminates part of the collapsibility. In a large number of engineering practices and applications in the past, the foundation treatment of many buildings (structures) is relatively shallow, and the treatment depth is usually below the foundation (3 ~ 5 m), so the residual collapsibility is still large, but there is no water immersion, and no foundation collapsibility problem has been found after years of use. At present, the loess code fails to cover the collapsible loess foundation with large thickness. Should the collapsibility of heavy weight collapsible loess with large thickness be completely eliminated? How deep is the foundation treatment to make the building safe? These problems are still the hot and difficult issues in the engineering design of loess area.

3.3. control of residual collapsibility of collapsible loess with large thickness

The collapsibility of loess can only occur after being immersed in water, and the amount of collapsibility is affected by the specific soil forming environment, causes, strati-graphic development,
geographical and geomorphic position, material composition, water content, compressive stress, especially its special structure, etc. Based on mathematical statistics, fuzzy mathematics and other theories, many Chinese scholars have established a relationship between collapsibility and its influencing factors. Dehua Zhang et al. studied the relationship between the collapsibility coefficient and the microstructure statistics, and gave the quantitative expression between them. Ruilin Hu et al. studied the fractal characteristics of loess structure by using the fractal structure theory, and believed that under the pressure and water driving, the soil structure transformed from high fractal dimension to low fractal dimension and resulted in the potential reduction, which was the microscopic change system of collapsible deformation. Through field tests, Jianzhong Sun et al. proved that once the loess is immersed in water, there will be many collapsible. In the current code, it is not reasonable to control the treatment depth of foundation only with the residual collapsibility (class b buildings should not be more than 150 mm, and class c buildings should not be more than 200 mm) on the site of self-weight collapsible loess. For some class b and class c buildings on collapsible loess sites with heavy dead weight of large thickness, even if the foundation treatment depth is greater than 15 m, not within the range of 150 ~ 200 mm. No matter how deep the foundation treatment is, it cannot reflect its rationality of technology and economy. On the site of collapsible loess with heavy dead weight of large thickness, no matter what foundation form is adopted for the construction of the structures, the whole piece treatment should be adopted for the foundation treatment, the whole piece treatment is better than the local treatment for the overall effect, and the control of residual collapsibility can also be relaxed appropriately. It is economically unreasonable to treat all residual collapsible loess as the treatment depth. Therefore, how much residual collapsible loess of large thickness can be controlled to meet the requirements of the specification? This problem is also an important task in the treatment of collapsible loess foundation with large thickness.

3.4. collapsibility of loess under different pressures
Whether the loess is collapsible or not and the degree of collapsibility are closely related to the pressure. In the engineering practice, it is found that some loess with different genesis and types show strong collapsibility under the action of lower pressure, while others need high pressure to show collapsibility. The treatment of collapsibility of loess under different pressure is one of the most common engineering geological problems in the loess plateau area.

3.5. humidifying shear deformation of collapsible loess
Collapsible loess has remarkable structure, and under the combined action of pressure and water, the collapsible deformation develops rapidly. Under the condition of natural low humidity, collapsible loess foundation, the loess slope, and ditch the shear strength is higher, has obvious high strength to adjust and low compressibility, flooding before mostly can is in a state of security and stability, once the flooding humidification, even the structure of the collapsible loess, reduce the intensity, can produce humidifying shear deformation even humidifying shear failure phenomenon. It can be seen that the humidification of loess does not necessarily reach saturation, and there exists the problem of intermittent loess collapsibility. Xuefeng Huang and Yichuan Xing et al. studied the humidification deformation law under different water content in the relevant papers, and systematically analyzed the humidification deformation characteristics of loess. In recent years, a lot of progress has been made in the study of constitutive relations of unsaturated loess. For example, a binary medium model of loess was proposed based on the concept of compound damage. Based on the viewpoint of soil mechanics, the structural model of loess was established, but the above model has many parameters, so the model needs to be further simplified. In addition, from the conventional stress path to a variety of complex stress paths, the law of humidification deformation needs to be further studied.

4. Conclusion
All kinds of special soils have special regional and structural features, and the complex and changeable geological environment will induce collapsible destruction of loess. In the past years,
China has accumulated rich experience and technical data in the treatment of collapsible loess, and obtained a number of effective and influential research results, occupying a foothold in the international geotechnical field. It is believed that in the future theoretical research and engineering practice, China will achieve more and better results in the field of special soil and provide strong scientific and technological support for the national infrastructure construction.

**Fund project:** The doctoral research fund project of LongDong university started in 2017  
**item number:** XYBY1707

**Reference**

[1] Kong, L.W. (2012) Review of special soil and slope technology development [J]. Journal of civil engineering, pp. 22-23.

[2] Chen, Y.Y. (1998) Correlation analysis of structural voids and collapsibility of loess [J]. Geological laboratory, pp. 49-51.

[3] Zhao, J.B, Chen, Y. (1997) Collapsibility of loess and its genesis [J]. Journal of geomechanics, 3(4):13-14.

[4] Shi, P.C. (2003) Collapsible loess foundation collapsible mechanism and foundation treatment method [J]. Western exploration engineering, pp. 55-56

[5] Chen, Z.H, Liu, Z.D. (1986) Collapsible deformation mechanism of loess [J]. Journal of geotechnical engineering, pp. 26-27.