Analysis of Collapsibility of Loess and Correlation Between its Indexes

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Abstract. The Guanzhong Plain city group is located in the centre of inland China, which is an important fulcrum of the Asia-Europe Continental Bridge, and also the second largest urban agglomeration in the western region of China. However, the large thickness collapsible loess has always been a pain point in the process of urban development. In this paper, for the problem of collapsible loess in Guanzhong area, five typical geomorphological units in Xi'an, Xianyang, Tongchuan and Sanmenxia are targeted for sampling. Through a large number of indoor and outdoor experiments, the relevant data of physical properties, hydrophysical properties, mechanical properties, collapsible index of collapsible loess and the distribution pattern of each index in the study area are analysed.By analyzing the correlation among the indexes, four indexes which are closely related to the collapsibility of loess are obtained: natural density, void ratio, dry density and saturation, and the regression analysis of these four indexes and the collapsibility coefficient is carried out respectively.This finding provides a reference for a more in-depth study of the characteristics of collapsible loess in Guanzhong area, and can optimise the engineering investigation process in urban construction, which is very important for the urban construction in this area.

Keywords: Collapsible loess; correlation; collapsibility coefficient; physical property index; hydraulic property index; mechanical property index regression analysis

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1 INTRODUCTION

The Guanzhong Plain city group [1], centred on Xi'an, is the starting point of the ancient Silk Road, and has a unique strategic position in the overall situation of national modernization and all-round opening pattern. On January 9, 2018, the State Council formally approved the Guanzhong Plain City Group Development Plan. As the Guanzhong Plain city group is located between the Loess Plateau and the Qinling Mountains, the regional geological landscape is complex, and has been greatly affected by collapsible loess over the years. With the rapid expansion of the city group, it is inevitable to carry out various types of large-scale urban construction in the area of collapsible loess [2]. Therefore, through a large number of indoor and outdoor tests, it is of great significance to obtain and analyse the test data of various indexes of loess in this area and find out the rules for the optimization of future engineering investigation [3].

In this paper [4], several typical geomorphic units in Guanzhong area were selected, and a large amount of data on loess indexes were obtained through indoor and outdoor tests. Among them [5], the indexes of physical properties include water content, natural density, dry density, void ratio, saturation. The indexes of hydrophysical properties include liquid limit, plastic limit, plasticity index. The indexes of mechanical properties include compression coefficient, compression modulus, and the indexes of collapsibility include collapsibility coefficient [6]. Then, through the analysis, the distribution law of each index was obtained, and the correlation between the indexes was discussed, and the indexes closely related to the collapsibility of loess in the region were derived [7]. At the same time, through the regression analysis of these indexes and collapsibility coefficient, the method of constructing the subsequent collapsibility prediction model of loess is found.

2 SITE OVERVIEW

Figure 1 shows the distribution of the five sites in this study. The five sites are all located in the typical geomorphological units of Guanzhong region and are representative. Site 1 geomorphological unit belongs to the loess ridge and depression area, located in the southeast of Xi'an City; Site 2 geomorphological unit belongs to the tertiary terrace on the south bank of the Yellow River, located in the west of Sanmenxia City; Site 3 geomorphological unit belongs to the loess tableland, located in the southwest of Tongchuan City; Site 4 geomorphological unit belongs to the secondary terrace on the left bank of the Wei River, located in the west of Xianyang City; Site 5 geomorphological unit belongs to the first grade terrace on the left bank of the Jing River, located in the northeast of Xianyang City.

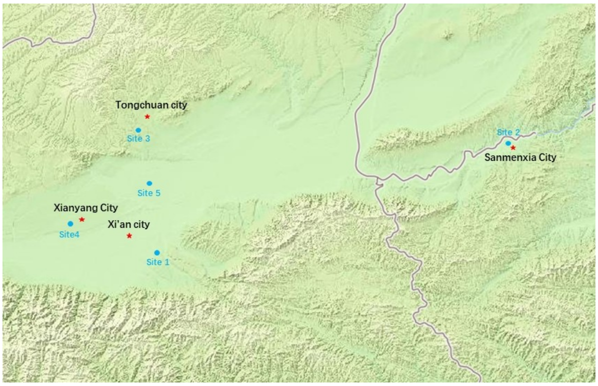

Fig. 1. Site distribution map for this study

3 STUDY ON INDEXES OF LOESS IN DIFFERENT GEOMORPHOLOGICAL UNITS

Loess has different genesis and overburden pressure at different depths, leading to differences in physical and mechanical properties and collapsibility. Therefore, this study selected five typical geomorphological units in Guanzhong area to investigate the physical property indexes, water-physical property indexes, mechanical property indexes and collapsibility indexes of loess at different depths, and the results are shown in Figure 2 .

Figure 2-(a) to Figure 2-(e) show the change rule of loess physical property indexes with depth. Figure 2-(a) shows the change rule of water content along the depth direction. With the increase of depth, the water content gradually increases. The water content of site 1, 3, 4 and 5 is between 12.9%-29.7%, and site 2 is between 5.4%-25.4%, which is a big change. The five sites belong to wet soil. Figure 2-(b) and Figure 2-(c) shows the change rule of natural density and dry density with depth of the five sitesIt can be seen that both have a similar trend, gradually increasing with the depth of the soil layer. The natural density is between 1.39-2.02, and the dry density is between 1.18-1.71. The void ratio of the soil in the study area shows a decreasing trend along the depth direction as shown in Figure 2-(d), which varies between 0.59-1.3. Figure 2-(e) shows the variation rule of saturation along the depth direction, it can be seen that the saturation of site 1, 3, 4 and 5 is between 27%-108%, and site 2 is between 17%-87%. The saturation gradually increases with the increase of the depth of the soil layer.

Figure 2-(f) to Figure 2-(h) show the change of loess water-physical property indexes with depth. The change rule of liquid limit and plastic limit of the five sites with depth is relatively similar, as shown in Figure 2-(f) and Figure 2-(g), along the depth direction of the whole from top to bottom to maintain in a more stable state. The loess liquid limit and plastic limit of site 1 fluctuated between 28.9%-36.0% and 17.7%-21.4%, respectively; site 2 fluctuated between 20.4%-26.4% and 13.7%-

17.5%, respectively; site 3, 4 and 5 fluctuated between 26.3%-33.5% and 16.1%-19.2%, respectively. From Figure 2-(h), it can be seen that the change rule of plasticity index of loess with depth is similar to the liquid limit and plastic limit, and it keeps fluctuating within a certain range from top to bottom along the depth direction. The fluctuation range of the plasticity index of site 1 is 11.2%-14.6%, site 2 is 6.7%-10.2%, and site 3, 4 and 5 is 10.2%-14.3%.

Figure 2-(i) and Figure 2-(j) show the change of loess mechanical property indexes with depth. With the increase of depth, the compression coefficient and compression modulus of loess both show the trend of increasing first and then decreasing. As shown in Figure 2-(i) and Figure 2-(j), the compression coefficient and compression modulus of site 1, 3, 4, and 5 increased first and then decreased between 0.1-0.76 and 2.84-18.63, respectively; site 2 increased first and then decreased between 0.07-1.05 and 1.9-26.39.

Figure 2-(k) shows the change rule of loess collapsibility coefficient with depth. With the increase of the depth, the collapsibility coefficient showed the trend of increasing first and then decreasing. The collapsibility coefficient of loess in site 1 ranged from 0 to 0.045, and all loess above 23m had collapsibility. The collapsibility coefficient of loess in site 2 ranged from 0 to 0.055, and all loess above 17.6m had collapsibility. The collapsibility coefficient of loess in site 3 ranged from 0 to 0.103, and all loess above 24m had collapsibility. The collapsibility coefficient of loess in site 4 ranged from 0 to 0.051, and all loess above 12m had collapsibility. The collapsibility coefficient of loess in site 5 ranged from 0 to 0.044, and all loess above 6m had collapsibility. As can be seen from Figure 2-(k), the collapsible soil layer in site 2 and 3 are thicker, both exceeding 17m, and most of them are located in the soil layer with moderate collapsibility and strong collapsibility, exceeding 16m. Therefore, the collapsibility grade of loess is IV. The collapsible soil layer of site 4 and 5 are thin and located in the region of weak collapsible soil layer. Although the collapsible soil layers of site 1 are thick, most of them are located in the region of weak collapsible soil layer. Therefore, the collapsible loess of site 1, 4 and 5 is grade II. It can also be seen from Figure 2-(k) that with the increase of depth, the collapsibility coefficient has a significant decrease and increase process, which is caused by the fact that there is a large amount of impermeable paleosoil layer mixed with the loess layer in Guanzhong area.

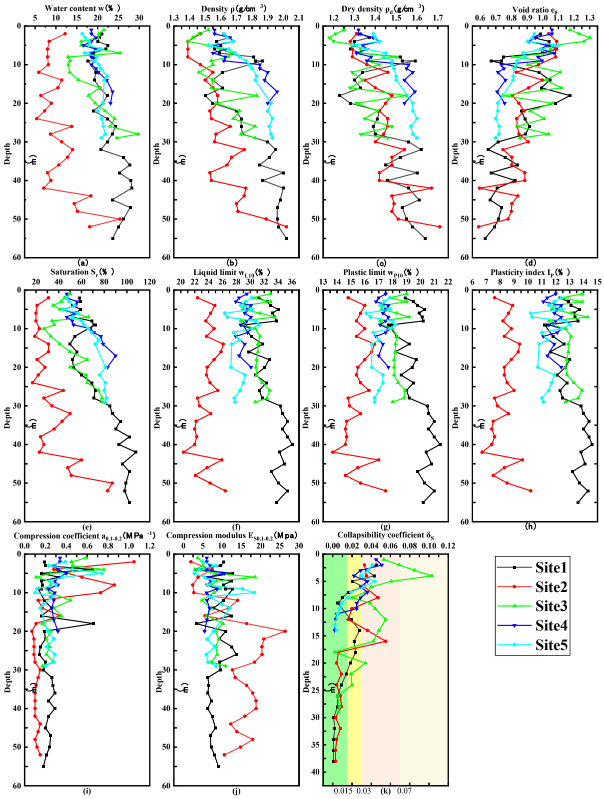

Fig. 2. Variation rules of indexes at different depths in five sites

4 CORRELATION ANALYSIS OF LOESS INDEX

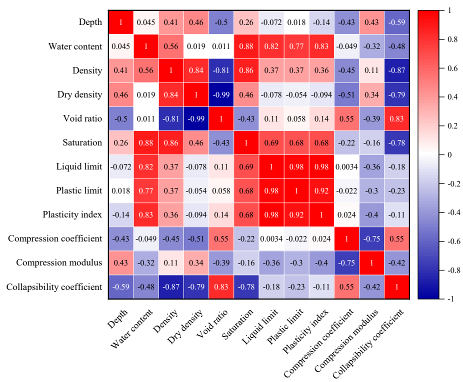

Fig. 3. Table of correlation coefficients between loess indexes and collapsibility coefficient

Table 1. Correlation degree grading table

Correlation degree	Weak	Medium	Strong
Absolute value of correlation coefficient	<0.4	0.4~0.7	>0.7

Using Pearson correlation analysis algorithm, the correlation degree between the above 11 loess indexes and the collapsibility coefficient of loess is evaluated, as shown in Figure 3 . The absolute value of the correlation coefficient is compared. According to the Table 1 , the indexes strongly correlated with the collapsibility coefficient are: natural density (-0.87), void ratio (0.83), dry density (-0.79) and saturation (-0.78). The depth (-0.59), compression coefficient (0.55)， water content(-0.48) and compression modulus (-0.42) were medium correlated with the collapsibility coefficient. The liquid limit, plastic limit and plastic index are weakly correlated with the collapse coefficient. At the same time, the indexes also affect each other. Water content and saturation、liquid limit、plastic limit、plastic index; Natural density and dry density, void ratio, saturation; Liquid limit and plastic limit, plastic index; Compression coefficient and compression modulus, all have a strong correlation.

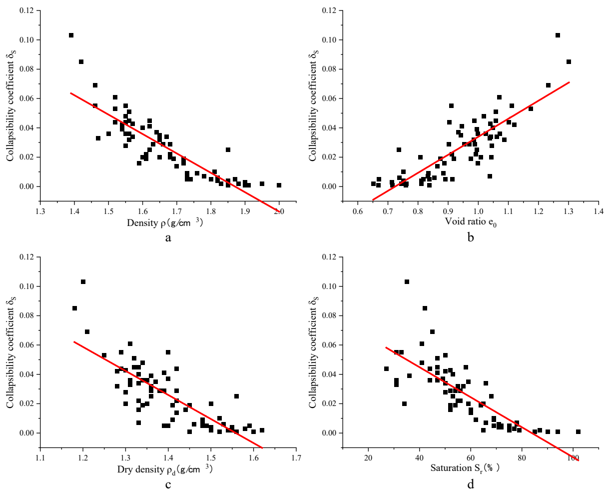

Fig. 4. Relationship between strong correlation indexes and collapsibility coefficient

Table 2. Regression analysis of strong correlation indexes and collapsibility coefficient

Indexes	Natural density	Void ratio	Dry density	Saturation
Equation	$\delta_S = -0.1322\rho + 0.2474$	$\delta_S = 0.1229e_0 - 0.089$	$\delta_S = -0.1639\rho_d + 0.2554$	$\delta_S = -0.001S_r + 0.0858$
Correlation coefficient	-0.868	0.831	-0.790	-0.776
R^2	0.754	0.690	0.625	0.601

Adjusted R^2	0.751	0.685	0.619	0.600

The above four strong correlation indexes and the collapsibility coefficient are separately analyzed by regression, as shown in Figure 4 and Table 2 . It can be seen that the fitting degrees of the regression equation established by the four indexes and the collapsibility coefficient are 0.754, 0.690, 0.625 and 0.601, respectively, which can explain the information of the collapsibility coefficients of 75.4%, 69.0%, 62.5% and 60.1%, indicating that the four collapsibility prediction equations of loess are valid. But the prediction of collapsibility coefficient is not sufficient. As can be seen from Figure 3, the collapsibility coefficient of loess is jointly affected by multiple indexes, so the regression equation of a single index and the collapsibility coefficient is not sufficient to fully express the collapsibility of loess. In the next step, I will further study these indexes and establish the collapsibility prediction equation of loess including multiple indexes

5 CONCLUSIONS

Aiming at the problem of collapsibility of loess in the process of urban construction in Guanzhong area, this paper obtained the distribution law of each index and collapsibility coefficient of loess in five typical geomorphic units through a large number of indoor and outdoor tests, analyzed the correlation between each index, and established a single linear regression equation of 4 strong correlation indexes and collapsibility coefficient.The conclusions are as follows: With the increase of soil depth, water content, natural density, dry density and saturation gradually increase; the void ratio gradually decreases; the compression coefficient, compression modulus and collapsibility coefficient first increase and then decrease; and the liquid limit, plastic limit and plastic index fluctuate within a certain range. Each index of loess is not independent of each other, but has a certain correlation. The four indexes that are closely related to collapsibility of loess are natural density, void ratio, dry density and saturation, and their correlation coefficients are -0.87, 0.83, -0.79 and -0.78, respectively. These indexes can explain the information of the collapsibility coefficient of 75.4%, 69.0%, 62.5% and 60.1% respectively, but the prediction of the collapsibility coefficient is still insufficient for practical application. In future studies, the multiple regression equation of loess collapsibility prediction model can be studied mainly based on the above indicators, so as to make more accurate prediction of loess collapsibility, simplify the tasks of geological survey, and promote the rapid development of urban construction.

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