ISSN:2790-1688 DOI: 10.56028/aetr.4.1.43.2023

Experimental study on engineering mechanical properties of loess-like backfill under various conditions

Xudong Wang[1,a] , Manman Qiu[2] , Xiaohui Li[2]

[1]Gansu institute of urban planning and design company limited, Gansu, Lanzhou,730070, China

[2]Key Laboratory of Disaster Mitigation in Civil Engineering of Gansu Province, Lanzhou University of Technology, Lanzhou 730050, China

[a] E-mail：19816876@qq.com

Abstract. Aiming at the loess-like backfill soil in the Lanzhou area, the samples with different compaction coefficients and different moisture content were prepared in the laboratory and tested by a double-line method. In the analysis of compression deformation, the pore ratio change rate is introduced, and the interval with the pore ratio change rate less than 10% is defined as the corresponding insignificant compression area. The corresponding compaction coefficient and water content of this area are summarized. The critical compaction coefficient is introduced in the analysis of collapsible deformation, according to which the subdivision is carried out, and the corresponding compaction coefficient and water content of the non-collapsible area are summarized. According to the variation curves of the subsidence coefficient under different compaction coefficients, the deformation mechanism of backfill soil after flooding is discussed. It is divided into two areas: water-compression area (low-pressure solid area) and water-subsidence area (high-pressure solid area).

Keywords: loess-like backfill; critical compaction coefficient for compression; necessary compaction coefficient for collapse; water-immersion compression; water-immersion collapse.

1. Introduction

With the expansion of urban space, there is less mature urban land, and the surrounding excavated and filled land is gradually used as construction land. With the deepening of engineering, settlement deformation and subsidence deformation of soil mass in excavation and filling sites are becoming more and more prominent, and deformation of filling areas has gradually attracted the attention of engineers and researchers.

Chen Zhenghan [1] earlier carried out a study on the deformation, strength, yield, and water variation characteristics of remolded unsaturated loess. Chen Kaisheng and Sha Aimin [2][3] conducted a series of studies on the compression and collapsibility deformation of compacted loess. They concluded that the collapsibility of remolded loess was greater than that of undamaged loess under low pressure, while the collapsibility of the two loesses was similar under high pressure. Compaction degree, moisture content, and age have significant influence on collapsibility of compacted loess. Huang Xuefeng et al. [4] and Yuan Kangfeng et al. [5] respectively analyzed the compression and collapsibility deformation characteristics of unaltered and remolded loess in Shanxi and Ningxia. It was generally believed that dry density, water content, and pressure had significant effects on the deformation characteristics, and soluble salt and age also had specific impact on the collapsibility. However, the influence laws of the above factors on loess in different areas vary to a certain extent.

The excavated and filled sites in the Lanzhou area are mainly located in the loess Liangmao area. The backfill materials in the loaded area are mostly loessial silt, Malan loess, and lishi loess, collectively called loessial backfill soil. Due to short site backfill time, poor soil uniformity, short consolidation, and other reasons. Therefore, it is impossible to accurately measure the physical and mechanical properties of backfill soil by current methods. In this paper, some experimental studies have been carried out on the loess-like backfill soil in the Lanzhou area through the indoor

ISSN:2790-1688 DOI: 10.56028/aetr.4.1.43.2023
double-line compression test, considering the test conditions of different compaction coefficient and different water content.

2. Test Samples

The test samples were taken from the large thickness backfill site in the Liangmao area of loess on the north bank of the Yellow River in Lanzhou City, belonging to silty loess. To ensure uniformity, all samples were taken from the exact location. The main physical indexes of soil samples are shown in Table 1.

Table 1 . The main physical parameters of test soil

Specific gravity Gs	Liquid limit wL/%	Plastic limit wP/%	Plasticity index Ip	Optimal water content wop/%	Maximum dry density ρdmax/g/cm3
2.70-2.71	23.5-27.1	16.4-17.2	7.1-9.9	16.4	1.75
HCO3(mg/kg)	SO42-(mg/kg)	Cl-(mg/kg)	Ca2+(mg/kg)	Mg2+(mg/kg)	Total soluble salt/%
252-376	99-245	914-1446	83-103	49-86	0.20-0.31

3. Trial Design

3.1 Test Protocol

According to the sample preparation method stipulated in the Standard of Geotechnical Test Methods (GB/T 50123-2019) [6], water content and compacting coefficient are taken as the control indexes for sample preparation. With the maximum dry density obtained by the light compaction test as a reference, the disturbed soil sample is air-dried and crushed, and passed through a 2mm sieve. The initial compaction coefficient λc is controlled as bare soil (the minimum compaction coefficient of a sample under the water content), 0.65, 0.70, 0.75, 0.80, 0.85, 0.90, 0.95 and 0.98, respectively. The water content ω is 0.0%, 5.5%, 7.6%, 10.3%, 13.0%, 16.2%, 17.6%, and 19.5%, respectively. The preparation of the soil sample is shown in Table 2.

Table 2 .Table of remolded loess sample preparation

Compacting coefficient λc	Moisture content w							
	0.0%	5.5%	7.6%	10.3%	13.0%	16.2%	17.6%	19.5 %
loose soil	0.58	0.50	0.50	0.62	0.61	0.63	0.67	×
0.65	√	√	√	√	√	√	√	×
0.70	√	√	√	√	√	√	√	×
0.75	√	√	√	√	√	√	√	√
0.80	√	√	√	√	√	√	√	√
0.85	√	√	√	√	√	√	√	√
0.90	√	√	√	√	√	√	√	√
0.95	√	√	√	√	√	√	√	√
0.98	×	√	√	√	√	√	√	√

Note: "×" indicates that the soil does not reach the specified compaction coefficient at this moisture content. In the case of barren earth, the sample is prepared directly on the instrument, and the reconstructed ground is empty-filled into the ring cutter to obtain the minimum compaction coefficient.

ISSN:2790-1688 DOI: 10.56028/aetr.4.1.43.2023

3.2 Test Operation Method and Data Processing

Double-line compression test, the implementation of the stage slow loading. In this experiment, water content and compacting coefficient were used as the main controlling factors, and an orthogonal comparison method was adopted. The test pressure levels are 50KPa, 100KPa, 200KPa, 300KPa, 400KPa, 500KPa, 600KPa, 800KPa, 1000KPa, 1200KPa, 1400KPa, 1600KPa, 1800KPa, 2000KPa. The stability standard of the sample before and after immersion is not more than 0.01mm/h.

4. Analysis of the Test Results

4.1 Compression Deformation Analysis

The variation curve of pore ratio with load under different initial water content is shown in Figure 1. λc=0.70,0.75,0.90,0.95, the pore ratio of soil sample decreases with the increase of water content when the initial water content ω<ωop, the minimum when the initial water content ω=ωop, and increases with the increase of water content when the initial water content ω>ωop. When λc=0.80,0.85, the pore ratio of the soil sample decreases continuously with the addition of water content, and the valley value of the pore ratio does not appear at the optimum water content. This indicates that the conclusion of maximum compression deformation at the optimum water content is not universally applicable, which is inconsistent with the conventional understanding.

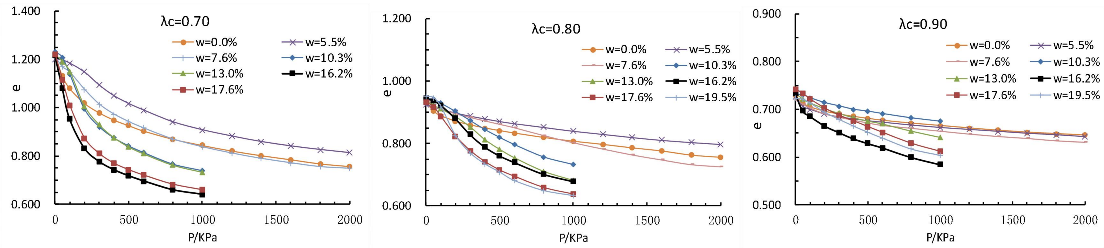

Fig1. The curves of pore ratio with load

The pore ratio reduction distribution curves under different initial compaction coefficients are shown in Figure 2. When λc<0.85, the pore ratio reduction curve fluctuates with the change in initial water content, and the distribution is loose, which indicates that the soil sample is more sensitive to water content. When ω<ωop, the void decrement curve increases with the increase in water content. When ω>ωop, λc=0.80, the 0.85 curve increases with the rise in water content, and other curve decreases with the growth of water content or tends to be stable. λc⩾0.85, with the rise of initial water content, the curve amplitude is small, and the distribution is compact in the interval of ω<10%, the curves almost coincide, and the pore ratio difference changes little with water content, indicating that the soil sample compression deformation in this region is weakly and sensitive to water content. In the range of 10%< ω<ωop, all curves gradually increase and tend to disperse with the increase of water content.This indicates that the water sensitivity of compressive deformation of soil samples is gradually enhanced. ω>ωop, and the distribution pattern of the curve is consistent with the above analysis.

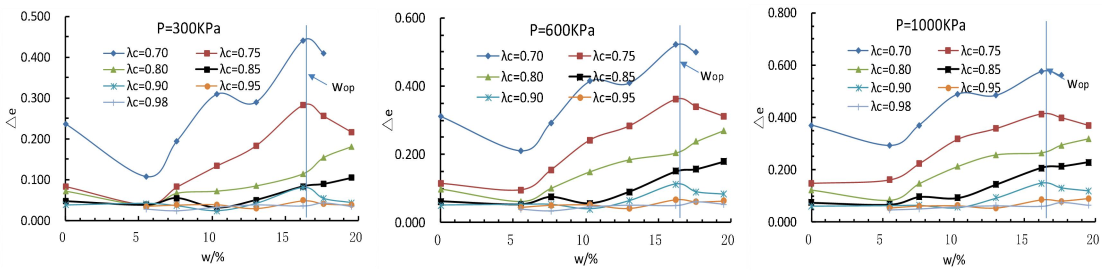

Fig2. The curves of the pore ratio increment with water content

ISSN:2790-1688
DOI: 10.56028/aetr.4.1.43.2023

The concept of "pore ratio change rate" is introduced here. Pore ratio change rate = (initial pore ratio-pore ratio under load)/initial pore ratio. The porosity ratio change rate was used to characterize the degree of compression response. According to previous research habits,a pore ratio change rate equal to 10% was taken as the dividing line. If the porosity ratio change rate was greater than 10%, the compression response was regarded as evident, and if it was less than 10%, the compression response was not noticeable. When the pore ratio change rate is equal to 10%, the compaction coefficient is defined as the "critical compaction coefficient of compression", and the curve of critical compaction coefficient changing with water content under different pressures is drawn, as shown in FIG. 3.

Under the same water content, the greater the load, the greater the critical compaction coefficient. Under the same bag, the greater the moisture content, the greater the critical compaction coefficient. The distribution curves under different pressures are similar in shape.They can be divided into three stages: 1. In the interval where ω is less than 10%, the critical compaction coefficient of compression varies little with water content; 2. 10%< ω<ωop, in which the critical compaction coefficient varies significantly with the increase of water content. 3. The interval of ω>ωop, within which the critical compaction coefficient almost does not change with the water content change.

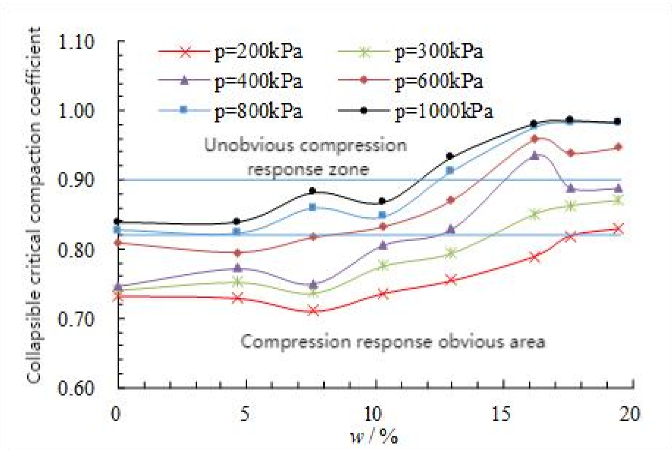

Fig3. The curves of compression's critical compaction coefficient with water content

As can be seen from Figure 3, when ω⩽12%, λ⩾0.81, the soil mass is located in the area where the compression response is not evident under 400KPa load. λ⩾0.90, the soil mass is located in the region where the compression response is not obvious under 1000KPa load.

4.2 Analysis of Collapsible Deformation

Collapsible deformation is one of the leading engineering characteristics of loess-like backfill soil. The curve of the collapsible coefficient with load under different initial moisture content is drawn, as shown in Figure 4. The collapsibility coefficient of varying water content under the same compaction coefficient tends to be the same under the condition of zero pressure; with the increase of the load, the collapsibility coefficient tends to increase or decrease, and tends to be stable gradually.

At the same moisture content, the collapsibility decreases with the increase of the load when the compaction coefficient is small, and tends to be stable when the load exceeds 1000Kpa; When the compaction coefficient is significant, the coefficient of collapsibility with the increase of gear, and tends to be stable after the load exceeds 1000KPa. The boundary point of compaction coefficient of collapsibility with the rise in moisture content, which is between 0.75 and 0.85.

When λc<0.80, the collapsibility decreases with the increase of water content ω<ωop; When water content ω=ωop, the collapsibility coefficient reaches the minimum; When water content ω>ωop, the collapsibility coefficient increases with the increase of water content.

When λc>0.80, the collapsibility coefficient decreases with the increase of water content, and there is no inflection point of the collapsibility coefficient at the optimal water content.

 ICBDEIMS 2023
DOI: 10.56028/aetr.4.1.43.2023

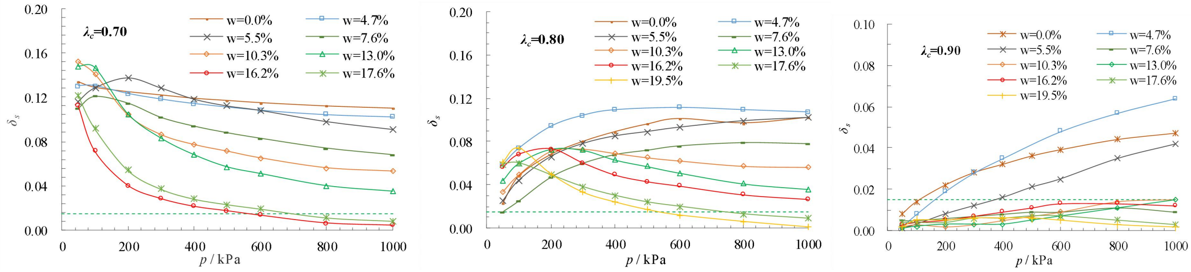

Fig4. The curves of collapsibility coefficient with load

The compaction coefficient at δs=0.015 is defined as the "Critical compaction coefficient of collapsibility," If the coefficient of compaction is greater than the critical coefficient of compaction, the soil will no longer be collapsible under a given load and moisture content, The curve of critical compaction coefficient with moisture content is drawn as shown in figure 5.

The distribution curves under different pressures are similar. They can be divided into three stages:1.In the range of ω<10%, the critical compaction coefficient decreases with the increase of water content, and the variation range is small;2.In the range of 10%<ω<ωop, the critical compaction coefficient hardly changed with the change of moisture content;3.In the range of ω>ωop, the critical compaction coefficient was almost unchanged at low pressure (p<400KPa) and decreased sharply at high pressure (p>400KPa) .

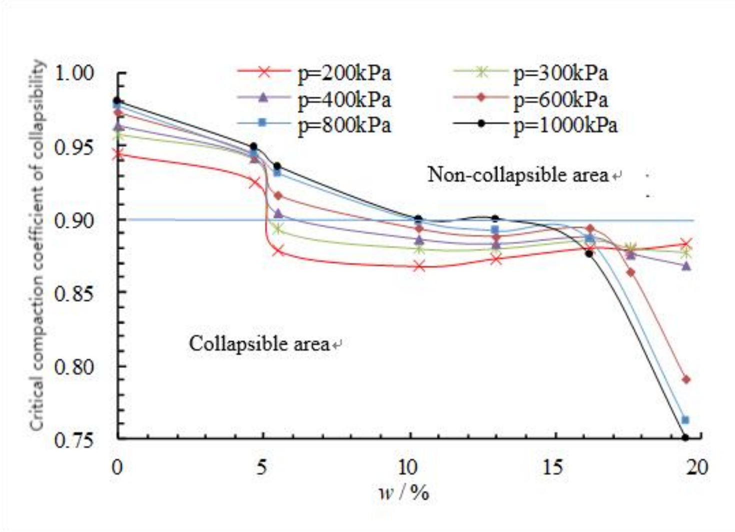

Fig5. The curves of collapse's critical compaction coefficient with water content

As can be seen from figure 5,The soils with ω⩾5.0% and λ⩾0.90 under small pressure (p⩽400KPa) are generally non-collapsible; Under the action of high pressure (p⩽1000KPa) , 5.0%⩽ω⩽10.0% and λ⩾0.95 or ω⩾10.0% and λ⩾0.90 are non-collapsible soils.

4.3 Analysis of Deformation Mechanism in Water Immersion

Figure 6 shows the distribution curve of collapsibility coefficient with compaction coefficient under different loads. According to the distribution of the curves, it is found that the curves under different loads converge at (tend to) a point at a certain compaction coefficient, and this point is called the critical point of compression collapsibility, according to which the curves can be divided into two regions: Water-immersion compression area (low compaction area) and water-immersion collapsible area (high compaction area).

Immersion compression zone: At the same compaction coefficient, the collapsibility coefficient decreases with the increase of load; With the increase of compaction coefficient, the collapsibility coefficient first appears peak value and then decreases gradually, finally tends to intersect at the boundary point. The collapsibility coefficient in this region is larger than that in the right region

ISSN:2790-1688 DOI: 10.56028/aetr.4.1.43.2023

under the same load. The deformation mechanism of this area is different from that of collapsible deformation. The collapsible coefficient is mainly controlled by the density of soil mass and caused by compressible pores after soaking.

Water immersion collapsible area：Under the same compaction coefficient, the bigger the load is, the bigger the collapsibility coefficient is; The larger the compaction coefficient is, the smaller the collapsibility coefficient is. Compared with the left area, the variation range is larger, eventually stabilized, the collapsible coefficient in the region is relatively small. With the increase of the compaction coefficient, the pores of the soil sample decrease, and the load is compacted, immersed compressible pores are further reduced, and the collapsible coefficient is mainly controlled by the load.

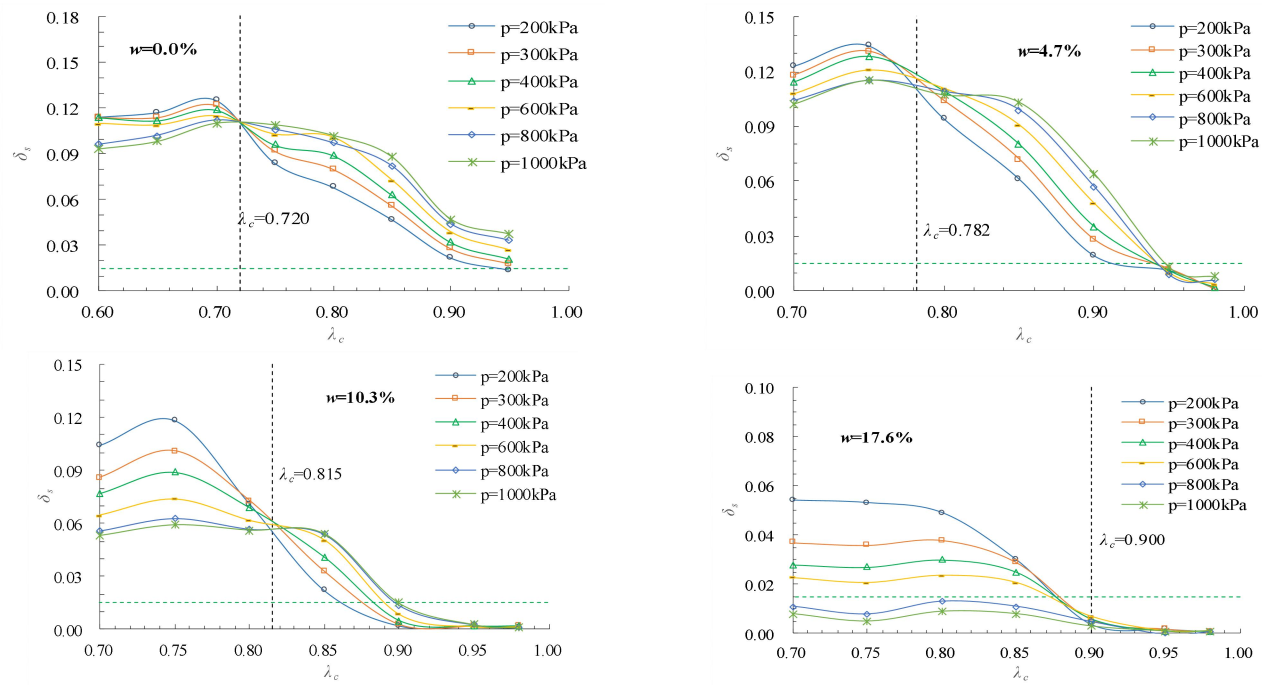

Fig6. The curves of collapsibility coefficient with compaction coefficient

As can be seen from Fig. 7, the critical point of compressional collapsibility is not constant, but increases with the increase of moisture content. Taking the distribution curve of the boundary point of compression collapsible as the boundary, it is divided into two regions, the upper part of the curve is regarded as the main influence area of the immersion collapse deformation, and the lower part of the curve is regarded as the main influence area of the immersion compression deformation. The coefficient of boundary compaction increases with the increase of moisture content, which is linear and has good correlation.

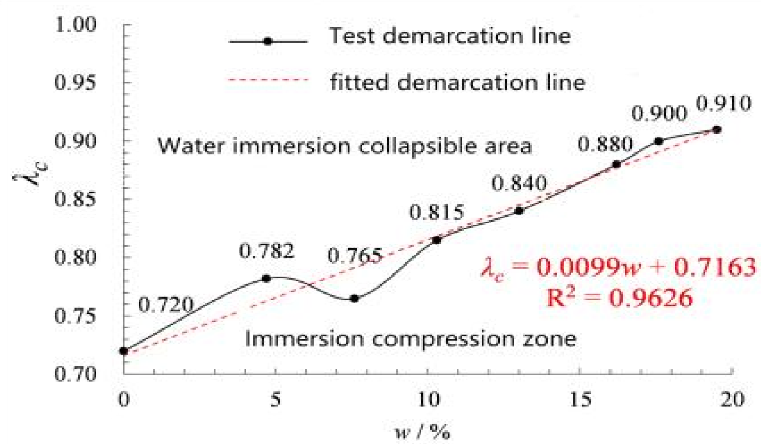

Fig7. The curve of demarcation point point with water content

ISSN:2790-1688 DOI: 10.56028/aetr.4.1.43.2023

5. Conclusion and Prospect

The conclusion of this paper：

(1) Loess-like backfill soil under small pressure (p≤400KPa), ω≤12% and λ≥0.81 ; Under high pressure (p≤1000KPa) , the change rate of pore ratio is less than 10% when ω ≤12% and λ≥0.90; In this case, the settlement and deformation of soil can be greatly reduced;

(2) Loess-like backfill soil under small pressure (p≤400KPa), ω≥5.0% and λ≥0.90 ; When 5.0%≤ω≤10.0% and λ≥0.95 or ω≥10.0% and λ≥0.90 under high pressure (p≤1000KPa) , the coefficient of collapsibility is less than 0.015. That is, the loess-like backfill has no collapsibility under the above conditions;

(3) The loess-like backfill with different compaction coefficients can be divided into water-immersion compression and water-immersion collapsibility according to the mechanism of water-immersion deformation. The immersion compression zone is dominated by immersion compression deformation, and the immersion collapsible zone is dominated by immersion collapsible deformation, the compaction coefficient increases with the increase of water content, and the relationship between them is basically linear.

In summary, for the loess-like backfill in Lanzhou area under the condition of natural water content (5.0%-10.0%) , under the action of small pressure (p≤400KPa) , from the angle of compression deformation, as long as the compaction coefficient λ≥0.81, the compression deformation can be greatly controlled; From the point of view of collapsible deformation, as long as the compaction coefficient λ≥0.90, the collapsible deformation can be controlled. This conclusion is of great engineering value in foundation treatment. It corrects the misconception that compressional deformation and collapsible deformation should be considered in all filling, the processing depth of large thickness filling area can be greatly reduced.

Acknowledgments

This work was financially supported by the Construction of science and technology projects of Gansu Provincial Department of Housing and Urban-Rural Development in 2021（JK2021-54）fund.

References

[1] CHEN Zheng-han. Deformation strength yield and moisture change of a remolded unsaturated loess[J]. Chinese Journal of Geotechnical Engineering,1999 (01):85-93.

[2] CHEN Kai-sheng, SHA Ai-min. Study of deformation characteristic of compacted loess[J]. Rock and Soil Mechanics,2010, 31(04):1023-1029.

[3] CHEN Kai-sheng, SHA Ai-min. Analysis of influencing factors of compacted loess collapsible deformation[J]. Journal of China and Foreign Highway,2009,29(3):24-28.

[4] HUANG Xue-feng, KONG Yang, LI Xu-dong, MA Long, YANG Bao-shan. Study and application of deformation characteristics of compacted loess[J]. Rock and Soil Mechanics, 2014,35(S2):37-44.

[5] YUAN Kang-feng, LI Zhi-juan, JIN Long. Correlation of loess compress modulus and collapsible[J]. Journal of Liaoning Technical University (Natural Science),2013,32(11):1480-1483.

[6] 《Standard for geotechnical testing method》（GB/T 0123-2019）.