Experimental Study on Engineering Properties of Large-Thickness Loess in Dongzhiyuan Area

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Abstract: In this paper, the engineering properties of collapsible loess with large thickness in Dongzhiyuan Area is analyzed in detail through consolidation test, triaxial shear test, maximum dry density test, static penetration test, standard penetration test and site wave velocity test. The results show that: (1) the engineering properties of Malan loess in the upper part of collapsible loess in Dongzhiyuan Area are not so satisfying. With the increase of the depth, the void ratio of the loess becomes increasingly smaller while the cohesive force and internal friction angle increase gradually. The bearing capacity of the foundation increases, indicating that the engineering properties of the foundation soil become better. (2) At the same time, the static lateral resistance and point resistance of the foundation soil become increasingly larger, which is very beneficial to the friction piles in the large-thickness collapsible loess area.

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1. Introduction
The central and western region of China is covered by the world's thickest and most extensive loess plateau, accounting for about 17% of the land in China [1]. The engineering properties of loess vary from region to region. Dongzhiyuan Area is located in Xifeng District, Qingyang City, Gansu Province. This area belongs to Zone II in the loess engineering geology division (The Eastern Gansu-Northern Shaanxi-Northern Shanxi District) [2], is the largest loess tableland in China. According to a large number of engineering survey data, the thickness of loess in this area is up to about 200m.

All the above mentioned researches mainly analyzed loess foundation treatment and the bearing capability of piles from the perspective of the collapsibility of loess. However, there are few researches focusing on the systematic study on engineering properties of loess, especially the compressibility, density and shear strength of Malan loess and Lishi loess. Therefore, there is no complete theory till now. In light of this situation, this paper, taking the site of a media center project in Xifeng District of Qingyang City as the test site, analyzes the engineering properties of large-thickness collapsible loess in Dongzhiyuan Area through a series of tests such as consolidation test, triaxial shear test, maximum dry density test, static penetration test, standard penetration test and site wave velocity test, expecting to provide references for the construction in large-thickness collapsible loess areas.
2. Overview of engineering geology in the test area

The test is carried out on the site of a media center project in Xifeng District of Qingyang City. The engineering geological profile of the site is listed as follows:

① Miscellaneous fill (Q₄ml): yellowish brown, dark brown, with a layer thickness of 0.20~1.40m, and a layer bottom elevation of 1382.91~1386.41m.

②-1 Loess-like silty clay and silt (Malan loess) (Q₃eol): yellow-brown, layer thickness 6.30 ~ 9.00m, layer top buried depth 0.20 ~ 1.40m, layer top elevation 1382.91 ~ 1386.41m.

②-2 Loess-like silty clay and silt (buried soil (Q₃eol)): brown red~reddish brown, with a layer thickness of 1.90 ~ 13.80 m, a top buried depth of 6.50 to 9.80m, and a top elevation of 1375.59 ~1378.82m.

③-1 loess-like silty clay (Lishi loess) (Q₂eol): brownish yellow~dark brown, layer thickness 0.70~4.80m, layer top buried depth 9.00~13.00m, layer top elevation 1369.32 ~1374.92m.

③-2 buried soil(Q₂eol): brown red ~ reddish brown, layer thickness 0.90 ~ 3.60m, layer top buried depth 12.00 ~ 17.00m, layer top elevation 1369.32 ~1374.92m.

③-3 loess-like silty clay (Lishi loess) (Q₂eol): brownish yellow, layer thickness 2.00 ~ 6.10m, layer top buried depth 14.50 ~ 19.50m, layer top elevation 1366.95~ 1371.16m.

③-4 buried soil (Q₂eol): brown, layer thickness 1.50 ~ 4.00m, layer top buried depth 17.50 ~ 22.60m, layer top elevation 1363.75 ~1366.06m.

③-5 loess-like silty clay (Lishi loess) (Q₂eol) layer: yellow~brownish yellow, layer thickness 3.00 to 4.60 m, layer top depth 20.50 to 23.80 m, layer top elevation 1361.91 to 1365.16 m.

③-6 buried soil(Q₂eol): brown red ~reddish brown, layer thickness 1.30 ~ 3.70m, layer top buried depth 24.00 ~ 27.40m, layer top elevation 1358.23 ~ 1361.51m.

③-7 loess-like silty clay (Lishi loess) (Q₂eol) layer: yellowish brown~sepi, layer thickness 4.10 ~ 5.60m, layer top buried depth 26.00 ~ 30.40m, layer top elevation 1355.89 ~ 1359.22m.

③-8 buried soil (Q₂eol): brownish red~ maroon red, layer thickness 1.60 ~ 3.20m, layer top buried depth 32.50 ~ 34.90m, layer top elevation 1330.29 ~ 1353.26m.

③-9 layer: loess-like silty clay (Lishi loess) (Q₂eol): brownish yellow, layer thickness 0.60~1.70m, layer top buried depth 35.7~36.70m, layer top elevation 1334.40 ~1335.16m.

③-10 buried soil (Q₂eol): brownish red~ maroon red, layer thickness 0.8 ~ 3.80m, layer top buried depth 36.8 ~ 38.40m, layer top elevation 1347.14 ~ 1348.96m.

③-11 layer: loess-like silty clay (Lishi loess) (Q₂eol): grayish yellow, layer thickness 0.60~1.50m, layer top buried depth 38.0~39.5m, layer top elevation 1345.12 ~1347.86m.

③-12 buried soil (Q₂eol): brownish red, layer thickness 0.80 ~ 1.30m, layer top buried depth 39.00 ~ 41.0m, layer top elevation 1343.62 ~1346.66m.

③-13 loess-like silty clay (Lishi loess) (Q₂eol): brownish yellow, layer thickness 10.20~14.40m, layer top buried depth 40.00~42.10m, layer top elevation 1342.52 ~1345.86m.

③-14 buried soil (Q₂eol): brownish red, layer thickness 0.9 ~ 2.30m, layer top buried depth 52.30 ~ 54.90m, layer top elevation 1330.10 ~1332.32m.

③-15 loess-like silty clay (Lishi loess) (Q₂eol): brownish yellow, layer thickness 2.10~2.90m, layer top buried depth 54.00~57.20m, layer top elevation 1328.34 ~1330.76m.

③-16 buried soil (Q₂eol): brown, layer thickness 0.60 ~ 3.20m, layer top buried depth 56.90 ~ 59.30m, layer top elevation 1326.20 ~1328.26m.

③-17 loess-like silty clay (Isolated from loess) (Q₂eol): brownish yellow, layer thickness 10.9m, layer top buried depth 59.20~60.50m, layer top elevation 1324.69 ~1325.60m.

③-18 buried soil (Q₂eol): reddish brown, layer thickness 3.50m, layer top buried depth 71.2m, layer
top elevation 1313.98m.

③-19 loess-like silty clay (Lishi loess) (Q2eol): brownish yellow, layer thickness 2.9m, layer top buried depth 74.70m, layer top elevation 1310.48m.

③-20 buried soil (Q2eol): reddish-brown, with a buried depth of 77.60m and a top elevation of 1307.58m.

3. Test plan and details

3.1 Indoor test

(1) Take the original samples every 1m in the borehole with an automobile drill, seal the samples and send them to the laboratory for following use. The on-site sampling is shown as in Fig. 1.

(2) Consolidation test, triaxial shear test, maximum dry density test, water content test, and loess collapsibility test was carried out with the samples.

3.2 On-site test

(1) Standard penetration test. After drilling to a predetermined depth, an in-situ standard penetration test is performed in the hole.
(2) Site wave velocity test. Four holes are selected in the site, and the wave velocity test is performed on the ground soil of the site with single hole method. In the test, a CJ-2000A suction-type three-component detector produced by Xi'an Electronic Instrument Factory was used. And its natural frequency is 28Hz. The collecting instrument FDP204s integrated motion tester used is produced by Institute of Rock and Soil Mechanics in Wuhan of the Chinese Academy of Sciences. The selected frequency bandpass of the instrument is 0.1-250Hz, and it has automatic gain and 1K sampling length.

(3) Static penetration test: select 10 points in the site to conduct static penetration test, as shown in Fig. 4.

4. Analyses of indoor test results

4.1 Consolidation test

Consolidation test was then conducted on soil samples to obtain the e–p curve of loess, as shown in Fig. 5.

It can be seen from the figure that as the depth increases, the void ratio of the loess decreases. At the same time, with the increase of the pressure, the void ratio of the loess decreases as well.

Under the same pressure, except for certain soil layers, the void ratio of Lishi loess at the lower layer is much smaller than that of the upper Malan loess.

Therefore, as the increase of the depth of loess foundation, the void ratio of the foundation soil gradually decreases, the compressibility of the foundation soil, accordingly decreases and the
engineering properties become much better.

4.2 Triaxial shear test
Triaxial shear test was carried out on loess soil samples collected at different depths. The cohesive force and internal friction angles of the soil samples were measured to obtain the distribution map of the shear strength and the depth of the soil samples, shown in Fig. 6.

Fig. 6 reveals that in the Malan loess section, the cohesive force of the soil is between 25 and 30 kPa, and the internal friction angle is between 28 and 29 degrees. In the section of Lishi loess, the internal friction of the soil increases with the depth. The angle gradually increases, which lies between 27° and 30°. Consequently, as the depth increases, the shear strength indexes of the foundation soil increases, and the shear strength increases as well.

4.3 Water content and dry density test
The compaction test was conducted on disturbed loess samples to determine the change rule of water content and dry density, as shown in Fig. 7.

Fig. 7(a) shows that the optimum water content of Malan Loess is 17.6% and the maximum dry density is 1.74g/cm³. It can be seen from Fig. 7(b) that the optimum water content of Lishi Loess is 18.9%, and the maximum dry density is 1.64g/cm³.

Therefore, the loess at different depths has little difference in the maximum dry density and the optimum water content from top to bottom, and the properties of the foundation soil almost remain unchanged.
4.4 The correlation between the collapsibility coefficient of loess and the depth of soil samples

Fig. 8: Collapsing coefficient change curve with depths

Figure 8 demonstrates the relationship between the collapsibility coefficient of loess and the depths under the pressure of 200 kPa. It is clear that the self-weight collapsibility coefficient of Malan loess is smaller than that of Lishi loess, and the collapsibility coefficient decreases with the increase of depth. So it is calculated that the loess of the site is self-weight collapsible, the collapsibility level of which is III. The loess type is of great collapsibility, and the lower limit of which is about 25.0 m.

4.5 Correlation between loess collapsibility coefficient and pressure

Figure 9 is the curve relationship between the collapsibility coefficient and pressure of Malan loess and Lishi loess at different depths.

Fig. 9(a) and (b) indicate that as the pressure increases, the collapsibility of the Malan loess and Lishi loess first increases and then decreases, and at 200 kPa, the collapsibility of loess is the largest.

4.6 Water content test

The water content of the soil samples of different depths was measured, and the relationship between the water content and the depth of the soil samples have been obtained and listed in Fig.10.
Fig. 10 Correlation between water content and depth

Fig. 10 demonstrates that the water content of the foundation soil is between 14% and 28% in the range of 70 m. The water content of Malan loess within 10 m increases first and decreases later while that of Lishi loess within 10 m – 25 m increases with depth. However, from 25 m to 50 m, it decreases with depth. Beyond 50 m, it suddenly increases again, which is mainly because the soil is under groundwater beyond 50 m, and the foundation soil is saturated.

Table 1 Statistical table of bearing capacity indexes of foundation soil

| Layer No. | Loess          | Foundation bearing capacity value $f_{ak}$ (kPa) | Compression modulus $E_s$ (MPa) |
|-----------|----------------|-----------------------------------------------|--------------------------------|
| ②-1       | Malan Loess    | 135                                           | 9                               |
| ②-2       | Malan Loess (Buried Soil) | 135                                           | 9                               |
| ③-1       | Lishi Loess    | 140                                           | 12                              |
| ③-2       | Lishi Loess (Buried Soil) | 140                                           | 12                              |
| ③-3       | Lishi Loess    | 160                                           | 15                              |
| ③-4       | Lishi Loess (Buried Soil) | 160                                           | 15                              |
| ③-5       | Lishi Loess    | 170                                           | 16                              |
| ③-6       | Lishi Loess (Buried Soil) | 170                                           | 16                              |
| ③-7       | Lishi Loess    | 170                                           | 16                              |
| ③-8       | Lishi Loess (Buried Soil) | 200                                           | 18                              |
| ③-9       | Lishi Loess    | 200                                           | 18                              |
| ③-10      | Lishi Loess (Buried Soil) | 200                                           | 18                              |
| ③-11      | Lishi Loess    | 200                                           | 18                              |
| ③-12      | Lishi Loess (Buried Soil) | 250                                           | 20                              |

5. Site test results analysis
5.1 Standard penetration test results
Table 1 is the reference values of the foundation soil bearing capacity indexes obtained in the standard penetration test according to project experience. It can be seen from Table 1 that with the increase of the depth, both the bearing capacity value and compression modulus of the foundation soil gradually increase. In general, the bearing capacity of Lishi loess is better than that of Malan loess.

5.2 Static penetration test results
Ten holes were selected from the site for static penetration test. And the average values of the static point resistance and lateral resistance of each layer were calculated. And accordingly, the change curve that static point resistance and lateral resistance vary with depth has been obtained and listed in Fig.11 and 12.

![Fig.11 Static point resistance with the change of depth](image1)

![Fig.12 Lateral resistance with the change of depth](image2)

Fig. 11 and Fig. 12 reveal that the static point resistance of the Malan loess within 10m is about 0.6 MPa, and the lateral resistance is about 10~19 MPa. The static point resistance of Lishi loess when it is 10m deeper is about 1.8 to 7.8 MPa. The lateral resistance of it is about 20~228 MPa. As can be seen from the two figures, both the point resistance and lateral resistance of the foundation soil gradually increase with the increase of the depth. Therefore, as the depth of the foundation soil increases, the bearing capacity of the foundation soil becomes better and better, which is very advantageous for the friction piles in the large-thickness collapsible loess area.

5.3 Site shear wave velocity test results

| Borehole No. | Measured Depth (m) | Covering Thickness (m) | Equivalent Shear Wave Velocity (m/s) | Value Range of Equivalent Shear Wave Velocity (m/s) |
|--------------|-------------------|------------------------|-------------------------------------|-----------------------------------------------|
| KT170        | 58                | >50                    | 219.4                               | 250≥Vse>150                                   |
| KT333        | 55                | >50                    | 233.9                               | 250≥Vse>150                                   |
| KT341        | 54                | >50                    | 229.5                               | 250≥Vse>150                                   |
| KT357        | 56                | >50                    | 228.6                               | 250≥Vse>150                                   |

Table 2 shows the shear wave velocity test results of the foundation soil in the site. It shows that the wave velocity value of the same type of site soil increases with the increase of the soil depth. According to the measured shear wave velocity values of various sites as well as the Code for Seismic Design of Buildings GB50011-2010, Malan loess and Lishi loess in the site are both medium soft.
6. Conclusion
(1) The engineering properties of Malan loess in the upper part of the large-thickness collapsible loess in Dongzhuyuan Area are not satisfying. With the increase of depth, the void ratio of Lishi loess gets smaller and smaller, the cohesion and internal friction angle gradually increase at the same time. The foundation bearing is gradually improved, and the engineering properties of the foundation soil are getting better and better.
(2) As the depth increases, the static point resistance and lateral resistance of the foundation soil become larger and larger. It is very advantageous for the friction pile in the large-thickness collapsible loess area.
(3) The large-thickness collapsible loess in Dongzhuyuan Area is a self-weight collapsible loess site, with a collapsible level of III, a serious degree of collapsibility, and a lower limit of which is about 25.0 m.

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