Calculation Method of Compressive Yield Stress: An Experimental Study of the Malan Loess, Xi'an Area, China

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Abstract

The structural characteristics of loess will change due to carbonate dissolution when loess is exposed to acid rain, industrial acid leakage and other acidic environments. The change of compressive yield well Characterization the initial structure of loess. To analyze the effect of initial water content on compressive yield of loess, confined compression tests and uniaxial compression strength tests were conducted on loess soils of five sets of water content, and the calculating method of compressive yield stress are given. The results show that the compression data of loess conform to the Gompertz equation, and the method to determine the maximum curvature point is given, which provides a new method to calculate the compressive yield stress.With the increase of initial water content, loess enters the compression yield state under lower water content, resulting in the failure of loess structure. This paper will contribute to elucidating the of loess.

Keywords

Yield stresses;loess;structure.

1. Introduction

Given the considerable development of China's western region and the acceleration of urbanization in the 21st century, eastern enterprises migrate west, leading to an increase in environmental pollution. The fragile ecological environment in the west faces severe challenges. Acid pollution is one of the most important environmental problems to address. According to statistics, the frequency of acid rain in the Xi'an area is 27.4%, and the area in which acid rain falls is expanding in northwest China. Industrial acid pollution is also an important environmental problem. Loess is a kind of metastable soil deposit rich in carbonate and is widely distributed in northwest China, accounting for approximately 6.6% of China's land area. Acids are known to easily react with carbonate:

$$H^{+} + CO_3^{2-} \longrightarrow H_2O + CO_2 \tag{1}$$

Calcium carbonate is an important inorganic cement in soil[1]. Calcite carbonate bonds tend to form the particle-to-particle contacts in the soil matrix, creating a cementing effect between soil particles[2]. Because the erosion of calcium carbonate in an acid-contaminated area changes the physical properties and structure of the soil, many soil properties, such as shear resistance and compression, are highly sensitive to the soil structure[3-5].

Gradually in the process of compression, the structural strength of loess, the soil structure under the load of compression curve with maximum curvature point compressive yield, the compressibility of loess before and after the structural compression yield very different, the existence of this turning point mutation of curvature is a reflection of the structural strength of soil, so the research of loess structural curvature has a special significance because of the traditional method to determine the turning point of human error is bigger [6-7], therefore, the solution of this point has been puzzled by scholars. A more accurate positioning of curvature mutation turning point is the premise of calculating yield stress.

2. Materials and Methods

2.1 Materials

For this experiment, Malan loess samples were collected from the Xi'an area of Shaanxi Province. The physical properties of the loess samples were determined by standard GB/T50123-1999: the water content was 9.3%, and the dry density was 1.47 g/cm^3. Five groups of samples were measured by the gas volume method: the average carbonate content was 108 g·kg^{-1} and the soluble salt content was 2.3 g·kg^{-1}. The basic physical indexes are given in Table 1.

Table 1. Physical properties of the unaltered samples

sample	Density/(g/cm^3)	specific surface area/(m^2/g)	Specific gravity	Atterberg limits/%		Particle size distribution/%		
				Plastic limit/%	Liquid limit/%	>0.075 mm	0.005–0.075 mm	<0.005 mm
Original soil samples	1.47	15.8772	2.726	22.27	35.34	2.78	73.06	24.16

The original samples were controlled to have the same initial water content. After drying at 105°C for 24 hours, the remoulded samples were placed in a drying box. An initial water content of 8% was imposed when the samples reached room temperature. The remoulded sample was prepared by compaction with a custom sample compaction instrument. The humidification process of the formed sample was completed by slowly adding distilled water by using a burette until the target water content was reached to retain the loess structure. The final water contents range from 8% to 24%. The water film transfer method was used to transform the samples with low water contents into samples with high water contents, and the natural air drying method was used to transform the samples with high water contents into samples with low water contents.

2.2 Confined Compression Test

Three types of specimens were subjected to lateral compression tests with a high-pressure consolidation apparatus. The tested values of pressure P were 50 kPa, 100 kPa, 200 kPa, 400 kPa, 800 kPa, 1600 kPa, and 3200 kPa. The experimental soil compression data (p and e) were fitted to the Gompertz (1825) equation by non-linear least squares fitting, as proposed by Gregory et al. (2006) [8]:

$$e = \mathrm{a} + c\exp\left\{-\exp\left[\mathrm{b}(\log\mathrm{p} - m)\right]\right\} \tag{2}$$

where e is the void ratio and p is the compressive stress.

The structural strength of loess is gradually tested in the process of compression, and the compressive yield of the soil structure is measured under the load corresponding to the maximum curvature point of the compression curve. The compressibility of the loess structure is very different before and after compressive yielding. The existence of this turning point is a reflection of the structural strength of the soil. Referring to Casagrande [9], the yield stress Psc of different loess compression structures can be obtained by determining the preconsolidation pressure.

The curvature function, k, is given as (e.g., Gregory et al., 2006):

$$K = \frac{d^2e/d(\log P)^2}{\left\{1+\left[de/d(\log P)\right]^2\right\}^{3/2}} \tag{3}$$

$$\frac{d\ e}{d(\log P)} = \left[bc\exp(-(\exp\ (\log P - m))))\right]\left[-\exp(b(\log P - m))\right] \tag{4}$$

$$\frac{d^2e}{d(\log P)^2} = \left[b^2c\exp(-(\exp\ \ b(\log P - m))))\right]\left[\exp(b(\log P - m))\right]\left[\exp(b(\log P - m))\text{ - }1\right] \tag{5}$$

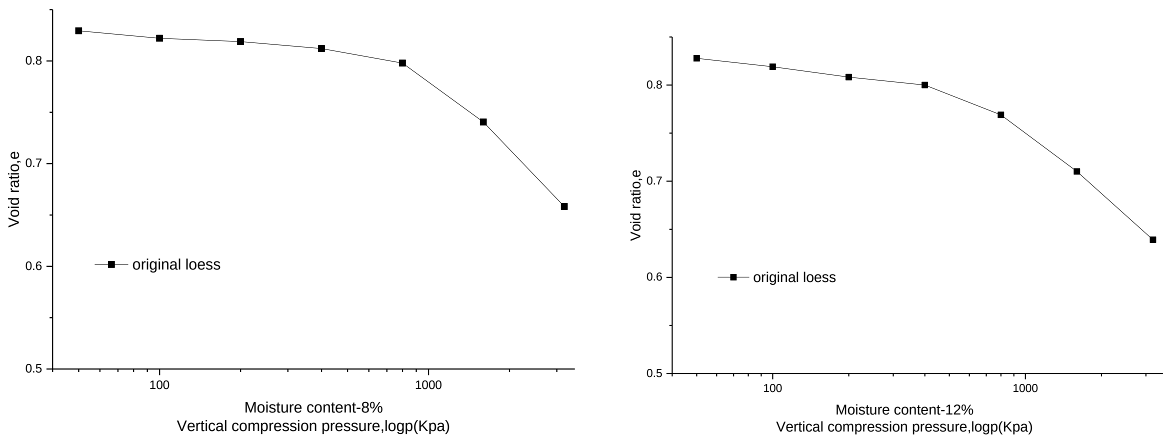
The consolidation yield stress was estimated as the stress at the point of maximum curvature of the compression curve. The maximum value of k and the corresponding value of P (i.e., P SC, which is P at the maximum K) were determined numerically.
Maximum curvature:

$$\frac{d\ K}{d(\log P)} = 0 \tag{6}$$

The point corresponding to the maximum curvature can then be found numerically.

3. Results

For the same initial bulk density sample, the water content increased as the degree of soil deformation and compaction increased (Fig. 1).



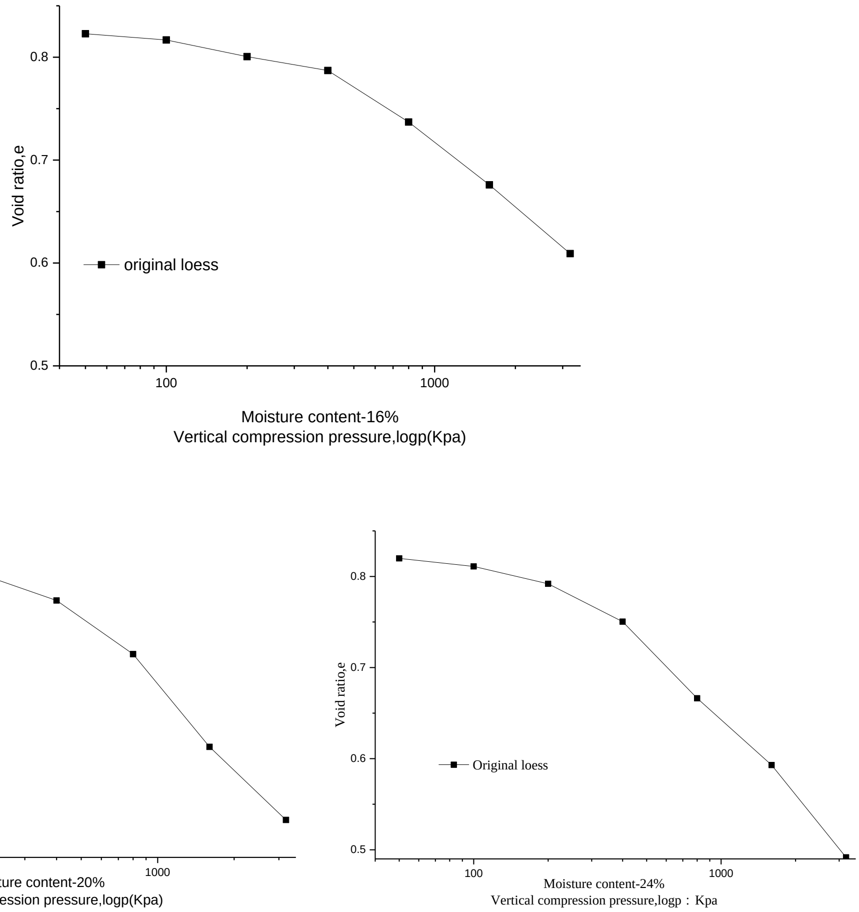


Fig. 1 e-lgp curves of of the loess with different water contents

Figure 2 shows that the Compressive yield stresses of the loess with different water contents . The yield stresses of the specimens decreased with increasing water content. However, the rate of decrease in the yield stress of the original loess gradually decreases as the water content increases. The yield behaviour of loess is closely related to the fracturing of the cemented bond, and its compressive yield is also regarded as the result of the fracturing of the bonds between particles. When the compression pressure is less than the yield stress, only a part of the bond fractures, and the change in porosity ratio is small. The bond between particles gradually breaks after the yield stress is reached. The bond between particles will be destroyed when the remoulded loess specimen is decompressed.

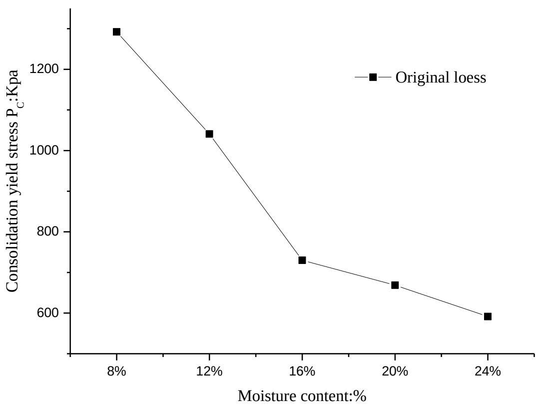


Fig. 2 Compressive yield stresses of the loess with different water contents

4. Conclusion

The compression data of loess conform to the Gompertz equation, and the method to determine the maximum curvature point is given, which provides a new method to calculate the compressive yield stress. with the increase of water content, loess structure entered the yield stage under lower pressure.

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