Abstract—The paper analyzes the express method of double-line method-based moistening deformation coefficient, which can be expressed as the strain difference with same pressure and different water contents. Through the analysis it is found that the key point of constructing moistening deformation coefficient bivariate model is to obtain the function relation of strain, stress and water content. And then, the paper discusses the concept of constructing moistening deformation coefficient bivariate model under confining compression test conditions. In combination with the specific test shows the bivariate model of moistening deformation coefficient realizing process. Finally, the verification test results show that the model is reasonable.

Index Terms—moistening deformation coefficient, model, method

I. INTRODUCTION

Loess is a kind of Quaternary-sediments, mainly distributed in arid and semiarid regions. Loess has a series of internal composition and external morphological characteristics due to the generation of specific environment, which is of silt, low density, vertical joints development, high soluble salt content and so on [1-4].

The large area in the northwest of china and the middle reaches of yellow river is covered with loess. The loess has different collapsibility due to its special engineering properties and structure characteristics. Because of its direct relation to the construction cost and safety, it has been an important issue in the field of geotechnical engineering. In recent years, with in-depth study of loess collapsibility, a large number of research results have been obtained [5-11]. The research emphasis of the loess collapsibility is gradually transferred from collapsible deformation to moistening deformation. Moistening deformation contains all deformation generated by humidification under pressure, the definition domain of which is wider than that of collapsible deformation. It is also called generalized collapsibility[6-8]. Water and loading are important conditions for loess moistening deformation. Therefore, the research on the effect of water and loading on loess collapsibility is one of the important subject of loess collapsibility.

This paper mainly discussed the basic method of constructing bivariate model considering moisture content and stress. Also combined with the specific test, it shows the realization process of the method and test the constructed model.

II. THE CONCEPT OF CONSTRUCTING DOUBLE-LINE METHOD-BASED MOISTENING DEFORMATION COEFFICIENT BIVARIATE MODEL UNDER CONFINING COMPRESSION TEST

The moistening deformation is refers to the additional settlement after the collapsible loess sinking stability under a certain pressure. The moistening deformation per thickness of soil samples is defined as moistening deformation coefficient [6]. Its expression is:

\[ \delta' = \frac{h_p - h'_p}{h_0} \]  

Where \( \delta' \) is moistening deformation coefficient; \( h_p \) is the height of soil after sinking stability under the action of pressure \( p \) when the initial moisture content is \( w_0 \); \( h'_p \) is the height of soil after sinking stability under the action of pressure \( p \) and moistening to moisture content \( w \); \( h_0 \) is the soil original height.

Usually, there are two research approaches in laboratory test for collapsible loess, namely, single line method and double line method. The double line method is widely used at present because of its briefness, less workload, strong comparative and so on. When the double line method is used to test moistening deformation coefficient, the type 1 can be written as:

\[ \delta' = \frac{h_p - h'_p}{h_0} = \frac{(h_0 - h'_p) - (h_0 - h_p)}{h_0} = \varepsilon_w - \varepsilon_\theta \]  

Where \( \varepsilon_w \) is soil strain under the pressure \( p \) when the water content is \( w \); \( \varepsilon_\theta \) is soil strain under the pressure \( p \) when the initial water content is \( w_0 \). That is the double-line method-based moistening deformation coefficient can be expressed as the strain difference with same pressure and different water contents.

As shown in (2), the key point of constructing moistening deformation coefficient bivariate model is to obtain the function relation of strain, stress and moisture content (

\[ \varepsilon = f(\sigma, w) \]).

The typical relationship curve of soil strain - stress under confining compression test is shown in Figure 1.
As is shown in the Figure 1, the relationship curve of soil strain - stress under confining compression test is hyperbolic, its expression can be shown as in (3):

$$\varepsilon = \frac{-\sigma}{a + b \sigma}$$  

(3)

Where $a$ and $b$ are the test parameters.

In (3), the influence of moisture content on the soil strain - stress relationship under confining compression test can be shown in the test parameters $a$ and $b$. Therefore, as long as the influence of moisture content on relationship of soil strain - stress separated from the parameters $a$ and $b$, the function relation of strain and stress, and moisture content can be established.

If the test parameters are $a$ and $b$ under confining compression test when the moisture content is $w$; the test parameters are $a_s$ and $b_s$ when the soil is saturated. The water content and the ratio of test parameter $a$ and $a_s$ have a functional relationship. It can be written as ($a/s$).

$$a = a_s \frac{a}{a_s} = a_s \frac{j(w)}{a_s}$$  

(4)

Likewise, The water content and the ratio of test parameter $b$ and $b_s$ also have a functional relationship. It can be written as ($b/s$).

$$b = b_s \frac{b}{b_s} = b_s \xi$$  

(5)

So the general relational expression of soil strain - stress can be written as:

$$\varepsilon = \frac{\sigma}{a_s j(w) + b_s g(w) \sigma}$$  

(6)

This proves that once the concrete expression of $a = f(w)$ and $b = g(w)$ are given, the equation (6) can be determined. By substitution of (6) to (2), the bivariate model of double-line method-based moistening deformation coefficient can be established as follows:

$$\delta'_e = \varepsilon_w - \varepsilon_0$$  

$$\sigma = \frac{a_s j(w) + b_s g(w) \sigma}{a_s j(w) + b_s g(w) \sigma}$$  

(7)

Then this paper shows the bivariate model considering moisture content and stress of moistening deformation coefficient realizing process in combination with the specific test.

III. THE CONSTRUCTION OF BIVARIATE MODEL

A. Test method and test data

The soil samples used in the test are from Yangling City in Shanxi Province and Lanzhou City in Gansu Province. The soil samples of Yangling are taken from 3m depth of second terrace of Wei River. Its natural moisture content is 19% obtained by drying measured. Its dry density is 1.28 g/cm³ and saturated moisture content is 41%. The soil samples of Lanzhou are taken from 5m depth of YuZhong university town. Its natural moisture content is 5% obtained by drying measured. Its dry density is 1.4 g/cm³ and saturated moisture content is 35%. The test equipment is Triple consolidation apparatus. Using dripping with water make the moisture content of Yangling loess samples to 5%, 12%, 19%, 26%, 33% and 41%, and the moisture content of Lanzhou loess samples to 5%, 12%, 19%, 26% and 35%. Test data is shown in Figure 2.

B. The construction of the model

It can be seen from figure 2 that the relationship of soil strain -stress of Yangling and Lanzhou are a hyperbolic
The bivariate model of double-line method-based moistening deformation coefficient curve under confining compression test. The fitting results are shown in Table 1 obtained by (3) and the experimental data.

### Table 1.
The test parameters of strain-stress relationship curve with different loess

| Soil types      | Water content/% | a     | b     | R²   |
|-----------------|-----------------|-------|-------|------|
| Yangling loess  | 5               | 6447.80 | 12.18 | 0.99 |
|                 | 12              | 4252.42 | 0.89  | 1.00 |
|                 | 19              | 3156.80 | 1.47  | 1.00 |
|                 | 26              | 2538.02 | 1.83  | 1.00 |
|                 | 33              | 2144.71 | 2.19  | 1.00 |
|                 | 41              | 1761.49 | 2.58  | 0.99 |
| Lanzhou Loess   | 5               | 7761.37 | 22.62 | 0.99 |
|                 | 12              | 3403.84 | 3.63  | 0.96 |
|                 | 18              | 2318.13 | 2.03  | 0.97 |
|                 | 26              | 2045.48 | 2.00  | 1.00 |
|                 | 35              | 1644.79 | 1.87  | 0.98 |

Through analysing table 1 it is can be found the parameters a decreases with the increased moisture content. But the parameters b of Lanzhou loess and Yangling loess are different: the parameters b of Yangling loess increase firstly and then decrease with the increased moisture content; the parameters b of Yangling loess decrease gradually with the increased moisture content.

In order to obtain the concrete expression of \( \frac{a}{a_s} = f(w) \) and \( \frac{b}{b_s} = g(w) \), \( a_s \) and \( b_s \) should be calculated firstly. And then the curve of \( \frac{a}{a_s} \) and \( \frac{b}{b_s} \) are drawn in Figure 3.

It can be seen from the Figure 3 that the relationship curves of \( \frac{a}{a_s} \) and \( \frac{b}{b_s} \) can be expressed with the secondary fitting of Bertalanff curve, its expression is \( y = A(1 - Be^{-Cx})^2 \). The fitting parameters are shown in Table II.

According to this, the bivariate model of the relationship of soil strain-stress of Yangling and Lanzhou, as shown in (8).

\[
\varepsilon = \frac{\sigma}{a_s A(1 - B e^{-C x})^2 + b_s A_i(1 - B e^{-C x})^2} \sigma
\]

For the loess in Yangling:

\[
\varepsilon = \frac{\sigma}{1444.42(1+1.5(10^{-0.02})+2.12(1-15e^{-20.08}))} \sigma
\]

For the loess in Lanzhou:

\[
\varepsilon = \frac{\sigma}{1340.97(1+3.97e^{-1.15})+1.87(1-14e^{-33.34})} \sigma
\]

The moistening deformation coefficient can be obtained by substituting (8) into (7), that is:

\[
\delta' = \varepsilon_w - \varepsilon_0
\]

\[
= \frac{\sigma}{a_s A(1 - B e^{-C x})^2 + b_s A_i(1 - B e^{-C x})^2} \sigma
\]

And then the soil moistening deformation coefficient of Yangling can be expressed in (12):
The soil moistening deformation coefficient of Lanzhou can be expressed in (13):

\[
\delta' = \varepsilon - \varepsilon_0 = \frac{\sigma}{1644.79 \times 0.87(1 + 3.97e^{-11.35\sigma})^2 + 1.87(1 - 14e^{-33.34\sigma})^2} \sigma
\]

\[
\delta' = \varepsilon - \varepsilon_0 = \frac{\sigma}{1430.97(1 + 3.97e^{-11.35\sigma})^2 + 1.87(1 - 14e^{-33.34\sigma})^2} \sigma
\]

IV. CONCLUSION

The soil moistening deformation coefficient obtained by the double line method can be expressed the strain difference with same pressure and different water contents. Through the analysis it is found that the key point of constructing moistening deformation coefficient bivariate model is to obtain the function relation of strain, stress and water content. The specific expression of soil moistening deformation coefficient bivariate model is established by the data obtained under confining compression test in Yangling loess and Lanzhou loess. The verification test for the model shows that the soil moistening deformation coefficient bivariate model is reasonable.

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<Figure 4. The compare Test data and calculated data>