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# Researching Characterization of Adsorbed Water Parameters Based on Macro - mechanics Index

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**Abstract.** The adsorbed water formed on clay minerals particle surface is an important microscopic physical factor that remarkably influences the physical condition, the strength and deformation of engineering characteristics of clay. Quantitative description of the relevant parameters associated with adsorbed water has an important theoretical significance. Clay can present different physical states, by analyzing the relationship between the adsorbed water content and different physical states, the connection between the adsorbed water mass and Atterberg limits was built, and the relevant expression was derived. On this basis, assumed that the clay particles are platy, then, the formula of the adsorbed water thickness was deduced. A new way to quantify the microscopic parameters using macroscopic physical mechanics index was opened up.

## 1. Introduction

The surface of the clay mineral particles is charged and an electric field is formed around the particles. After encountering water, under the action of the electrostatic field force, the positive ions and polar water molecules in the water will be adsorbed around the particles and align to form a water film. Usually this part of water is called adsorbed water[1].The presence of adsorbed water has a significant influence on the physical, chemical, and mechanical properties of clayey soils. It not only determines that cohesive soils can be used as a dominant factor in natural seepage control seepage materials, but also an important factor in inducing a series of clay soil engineering problems. Therefore, the associated properties of adsorbed water are one of the key research topics in soil mechanics, geotechnical science, soil science, engineering geology, environmental geology, colloid chemistry, and mineralogy.

The characteristics of the adsorbed water, the form of attachment, diffusion, fluidity and permeability are the control of physical and mechanical properties such as the plasticity of the clay, hydration expansion, dispersion, shrinkage, specific surface area, pore structure, micro-surface structure, soil-water characteristic curve, and strength, and other important factors of electrochemical properties such as pH, conductivity, heat of adsorption, Zeta potential, exchangeable cations, and exchange of cations. Wu Fengcai and Li Wenping et al. [2-5] used the volumetric flask method to determine the adsorption and binding of soft clay in different areas. Wang Pingquan [6-9] studied



ionization, infrared spectroscopy, isothermal adsorption, and thermogravimetric analysis of the characterization and type definition of adsorbed water on cohesive soils. Cui Deshan, Xiang Wei, et al. [10] analyzed and calculated the change of the thickness of bonded water of red clay soil before and after treatment with ion soil solidifying agent (ISS). Wang Tiexing [11] combined the isothermal adsorption method and the thermogravimetric analysis method to classify and limit the adsorbed water on the surface of Xi'an Q3 loess. Stepkowska and Mojid [12-13] studied the change in thickness of different montmorillonite particles after adsorption of adsorbed water, and the ability of water content and temperature to exchange cations with water.

The above research results all have important theoretical significance, but there are also problems such as complicated operation, high cost, and cumbersome calculations. Therefore, this paper bridges the macro-indicators of the physics and mechanics of cementitious soils and the microscopic parameters of the adsorbed water, and opens up a new way to the adsorbed water content and thickness with a more accurate and convenient method.

## 2. Formation and Properties of Adsorbed Water

In the surface of cohesive soil particles are usually negatively charged, an electric field is generated around them. When the soil particles meet water, the water molecules will polarize under the electrostatic attraction of the surface and adsorb around the soil particles to form a water film. Usually this part of water is called the adsorbed water film on the surface of the soil particles. The electrostatic attraction of water molecules decreases with the distance from the surface of soil particles. The adsorbed water closest to the surface of soil particles is tightly adsorbed around the soil particles, which is called strongly adsorbed water; It is called weakly adsorbed water; water molecules farther from the surface of soil particles are controlled only by the action of gravity and are almost unaffected by the electrostatic attraction, which is called free water [14].

Strongly adsorbed water, its properties are controlled by electrostatic attraction, almost completely fixed arrangement, loses the characteristics of the liquid, has great viscous resistance, almost no fluidity, the freezing point is lower than  $0^{\circ}\text{C}$ , the density is greater than that of free water, and it has creeping transsexual.

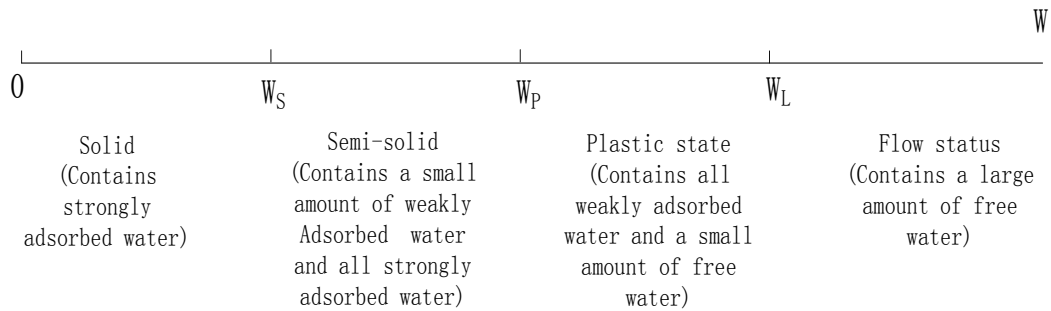
Weakly adsorbed water, its nature is also affected by the electrostatic attraction, oriented around the particles, the electric field force weakens away from the particles. When it is stressed, it can be slowly transferred from the thicker part of the water film to the thinner part of the water film. Can deform, but does not flow due to its own gravity. Its existence is the reason why clay soil shows plasticity within a certain water content range.

## 3. Combination of Adsorbed Water and Consistency Indicators

### 3.1. Liquid Limit Characterizes Adsorbed Water Content

The study by Cui et al. [10,15,16] showed that when the water content is  $0 < W \leq W_p$ , most of the clay soil is strongly adsorbed water, and there is little weakly adsorbed water. When the water content is  $W_p < W \leq W_L$ , most of the clay soil is weakly adsorbed water, and a small amount is free water; when the water content is  $W \geq W_L$ , there is a large amount of free water in the clay soil, as shown in Figure 1. Among them,  $W$  is the water content of clay soil,  $W_p$  is the clay soil plastic limit, and  $W_L$  is the clay soil liquid limit.

There is no exact one-to-one correspondence between the physical state of the clay and the boundary water content. Li Wenping et al. [3] showed that the upper bound of the strongly adsorbed water content of the cohesive soil is about 0.885 times of the plastic limit; Wang Pingquan [6] studying for the calcium-sodium montmorillonite clay, it was found that the bound of strongly adsorbed water and weakly adsorbed water was 0.9 times of the relative water vapor equilibrium pressure.



**Figure1.** Physical state of cohesive soils and water content

Based on the above conclusions and the purpose of this study, the following assumptions are made for saturated clay: (1) crystal water content of soil particles is not counted; (2) the order of priority for humidification of pore water in the soil is strong binding water, weak binding water, and free water; (3) the soil particles are connected by means of adsorbed water; (4) the soil particles and water are incompressible; (5) the strongly adsorbed water content of cohesive soil is in the range of  $0 \sim W_P$ , the weakly water content in the range of  $W_P \sim W_L$ , the entire adsorbed water content is in the range of  $0 \sim \alpha W_L$  ( $0 < \alpha < 1$ ). That is, the plastic limit of cohesive soil is equivalent to the upper bound of strongly adsorbed water content or the lower bound of weakly adsorbed water content, and the upper bound of weakly adsorbed water content is smaller than the liquid limit of soil mass, which is equivalent to the liquid limit of cohesive soil multiplied by reduction factor  $\alpha$ . In this way, the plastic limit and liquid limit of clay soil are known, and the content of adsorbed water in clay soil can be deduced. The specific derivation process is as follows.

The mass of soil particles in clay soil:

$$m_s = \rho_s V_s \quad (1)$$

Where:  $V_s$  is the total volume of soil particles (cm<sup>3</sup>),  $\rho_s$  is the density of soil particles (kg · cm<sup>-3</sup>).

Defining the water content of adsorbed water in cohesive soil:

$$W_{aw} = \frac{m_{aw}}{m_s} = \alpha W_L \quad (2)$$

The quality of the adsorbed water in the available soil is:

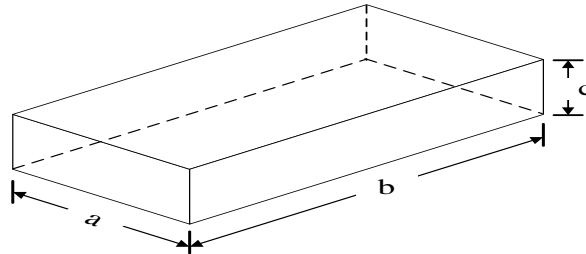
$$m_{aw} = m_s W_{aw} = \alpha \rho_s V_s W_L \quad (3)$$

In the formula,  $\alpha$  is the ratio of the adsorbed water mass in clay soil to the total mass of pore water when the soil is just at the liquid limit ( $0 < \alpha < 1$ ) is called the proportional coefficient of adsorbed water in the liquid limit,  $\alpha$  can be calculated with the help of thermal weight loss test, high-speed centrifugal test and other methods. It is usually desirable  $\alpha = 0.9$  [17].

From formula (3), it is not difficult to see that the quality of adsorbed water is positively related to the liquid particle quality and consistency indicator liquid limit. These two macro-physical and mechanical indicators can be accurately obtained through indoor tests with reference to "Standard for Geotechnical Test Methods" (GB/T 50123-1999), and the quality of adsorbed water can be further calculated. The establishment of this equation enables the use of easy-to-measure indicators to characterize the goal of microscopic parameters of adsorbed water.

### 3.2. Liquid Limit Characterization of Adsorbed Water Thickness

Since the cohesive soil particles are mostly in a sheet structure, such as montmorillonite is in the form of flakes and kaolinite is flat. You can assume it is a single-particle, uniform cuboid, as shown in Figure 2.



**Figure2.** Dimensions of a platy particle

The volume of clay soil particles (without adsorbed water) is:

$$V_{es} = abc \quad (4)$$

In the formula, a, b, c respectively represent the width, length, and thickness of clay particles. The surface area of soil particles is:

$$A_s = 2(ab + bc + ac) \quad (5)$$

Clay soil contains the number of soil particles:

$$N = \frac{V_s}{V_{es}} = \frac{m_s / \rho_s}{abc} \quad (6)$$

The mass of adsorbed water by each cohesive soil particle is:

$$m_e = \frac{m_{aw}}{N} \quad (7)$$

Substituting equation (3) into equation (7) yields:

$$m_e = \frac{m_{aw}}{N} = \frac{\alpha \rho_s V_s W_L}{N} \quad (8)$$

Substituting equations (4) and (6) into equation (8), respectively, results in:

$$m_e = \frac{\alpha \rho_s V_s W_L}{N} = \alpha \rho_s V_{es} W_L = \alpha \rho_s abc W_L \quad (9)$$

The adsorbed water volume by each cohesive soil particle can be expressed as:

$$V_e = \frac{m_e}{\rho_{aw}} \quad (10)$$

Substituting formula (9) into formula (10), we can sort out:

$$V_e = \frac{\alpha \rho_s abc W_L}{\rho_{aw}} \quad (11)$$

Assuming that the cohesive soil particles are flat, as shown in Fig. 3, and the combined water thickness is  $t$ , the adsorbed water volume adsorbed by each cohesive soil particle can also be expressed as:

$$V_e = (a + 2t)(b + 2t)(c + 2t) - abc = 2t(ab + ac + bc) + 4t^2(a + b + c) + 8t^3 \quad (12)$$

In equation (12),  $t^2$  and  $t^3$  respectively represent the area and volume of adsorbed water at the corners of the cohesive soil particles. The clay particles at the corners have the smallest charge density and the least adsorbed adsorbed water. Therefore, this part is negligible and is regarded as  $t^2 \rightarrow 0$  and  $t^3 \rightarrow 0$ . That is, equation (12) can be rewritten as:

$$V_e = 2t(ab + ac + bc) \quad (13)$$

By making equations (11) and (13) equal, the maximum thickness of adsorbed water can be obtained.

$$t = \frac{\alpha \rho_s abc W_L}{2 \rho_{aw} (ab + bc + ac)} \quad (14)$$

According to the geometry of cohesive soil particles, the specific surface area can be expressed by the following formula:

$$S = \frac{A_s}{m_s} = \frac{2(ab + bc + ac)}{abc \rho_s} \quad (15)$$

Thus, substituting equation (15) into equation (14) further rewrites:

$$t = \frac{\alpha W_L}{S \rho_{aw}} \quad (16)$$

Equation (16) reflects that the thickness  $t$  of the adsorbed water is related to four parameters, where  $\alpha$  can be approximately considered as an empirical constant, and the remaining three parameters have a clear physical meaning and can be accurately measured by the test. When  $\alpha$ ,  $S$  and  $\rho_{aw}$  are constant,  $t$  increases with the increase of  $W_L$ , that is, the greater the liquid limit, the thicker the adsorbed water in the soil, which is consistent with the actual. The establishment of this expression provides a convenient and feasible new way to calculate the combined water thickness.

#### 4. Concluding Remarks

Due to the presence of adsorbed water, the properties of infiltration, consolidation, and creep of clayey soil are different from those of other soils. Therefore, quantitatively describing the related parameters of adsorbed water not only has high academic value, but also has important guidance. Based on the macroscopic physical mechanics and macroscopic physical state indicators that can be easily and accurately measured, this paper respectively derives the microscopic adsorbed water content expression and the adsorbed water thickness expression. The parameters contained in the formula are of clear physical meaning and verified. The feasibility and rationality of quantifying microscopic parameters using macro-indicators were demonstrated.

#### 5. References

- [1] Li Guangxin, Zhang Bingyin, Yu Yuzhen. Soil mechanics[M]. Beijing: Tsinghua University Press, 2013.
- [2] Wu Fengcai. Adsorption of cohesive soils combined with some characteristics of water measurement and seepage[J]. Chinese Journal of Geotechnical Engineering, 1984, 6(6): 84-93
- [3] Li Wenping, Yu Shuangzhong, Wang Bairong, et al. Determination of adsorption-bonded water

- content in deep cohesive soils in coal mining areas and its significance[J].Hydrogeology and Engineering Geology,1995(3):31-34.
- [4] HE Jun,XIAO Shu-fang. Some Influence Of Bond Water On Rheological Properties Of Marine Soft Soils[J].Journal Of Jilin University(Earth Science Edition),2003(2):204-207.
- [5] Yuan Jianbin. The Study for Properties of Bound Water on Clayey Soils and Their Quantitative Methods[D].Guangzhou:South China University of Technology,2012
- [6] WANG Ping-quan. Determination Of Bound Water Boundary On Clay Surface By Isothermal Adsorption[J]. Journal Of Southwest Petroleum Institute,2005,27(6):57-61.
- [7] Wang Pingquan, Li Xiaohong. The Determination Of Bound Water Boundary On Clay Surface By Infrared Spectrum[J]. Journal Of Southwest Petroleum Institute,2006, 26(1): 80-83.
- [8] WANG Ping- quan,TAN Jing- ming, CHENG Di- kui. The Determination Of Bound Water Boundary On Clay Surface By Infrared Spectrum[J]. Journal Of Southwest Petroleum Institute, 2001, 23(2): 53-55.
- [9] WANG Pinquan. Determination Of The Types And Boundary Line Of Bound Water On Clay Surface By Ion Exchange[J].Journal Of Southwest Petroleum Institute,2000,22(1):59-61
- [10] CUI De-shan,XIANG Wei,CAO Li-jing,LIU Qing-bing. Experimental study on reducing thickness of adsorbed water layer for red clay particles treated by ionic soil stabilizer[J]. Chinese Journal of Geotechnical Engineering, 2010, 32(6):944-949.
- [11] WANG Tie-hang, LI Yan-long, Su Li-jun. Types and boundaries of bound water on loess particle surface[J].Chinese Journal of Geotechnical Engineering, 2014, 36(5): 942 – 947.
- [12] Stepkowska E T, Pérez-Rodríguez J L, Maqueda C, et al. Variability in water sorption and in particle thickness of standard smectites[J]. Applied clay science, 2004, 24(3): 185-199.
- [13] Mojid M A, Cho H. Effects of water content and temperature on the surface conductivity of bentonite clay [J]. Soil Research, 2012. 43(7): 767 – 777.(in Chinese)
- [14] Wu Qian. Research on Influence of Bound Water on Secondary Consolidation and Long Term Strength of Soft Clay[D]. Jilin Changchun: Jilin University,2015.
- [15] SINGH P N, WALLENDER W W. Effects of adsorbed water layer in predicting saturated hydraulic conductivity for clays with Kozeny- Carman equation [J]. Journal of Geotechnical and Geoenvironmental Engineering, 2008,134(6):829 – 836.
- [16] PROST R,KOUTIT T,BENCHARA A,et al. State and location of water adsorbed on clay minerals:consequences of the hydration and swelling-shrinkage phenomena[J]. Clays and Clay Minerals,1998,46(2):117 – 131.
- [17] DANG Faning,LIU Haiwei,WANG Xuewu,XUE Haibin,MA Zongyuan. Empirical Formulas Of Permeability Of Clay Based On Effective Pore Ratio[J].Chinese Journal Of Rock Mechanics And Engineering, 2015,34(9):1910-1917.