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The Cultivation of Innovation Ability in the Teaching of Soil Mechanics

Guojian Feng*, Jun Du, Weiwei Zhu, Zhigang Qiu

School of Urban and Rural Construction & Engineering Management, Kunming University, Kunming 650214, China.
fengguojian2000@163.com

In order to change the teaching model from “knowledge imparting” to “ability nurturing” through promoting students to learn and innovate and strengthening their abilities to solve practical engineering problems, this paper discussed the teaching of the calculation of the active earth pressure of cohesive soil based on Rankine earth pressure theory and of the judgment on the condition of earth’s limit equilibrium. Based on basic theories, figures and personal knowledge, this paper made necessary adjustment of teaching materials in line with students’ knowledge structure and proposed new opinions and ideas as to as stimulate students to learn more and enhance their abilities to analyze and solve problems by comprehensively using their knowledge.

1. Introduction

At present, China is pushing forward “The Plan of Teaching and Cultivating Excellent Engineers” with the purpose of enhancing students’ competence to innovate and apply knowledge to engineering practice so as to improve the talents’ quality through building talent cultivation model and innovating teaching methods and contents. Many universities have made many beneficial attempts in cultivating students’ innovating abilities till now, however, thorny problems still exist. This situation also applies to the teaching of soil mechanics in that students lacks innovation ability and capability of addressing problems via the principles and theories of soil mechanics. Therefore, to activate students’ innovative thinking and nurture their innovation ability, relevant practice and cultivation in this regard are essential for the teaching of soil mechanics.

2. The significance of soil mechanics

Soil mechanics, one of the theoretical foundations of civil engineering, is the science of studying the soil permeability, intensity and deformation as well as the rule by using knowledge of mechanics and geotechnical experimental techniques. As an extensive and comprehensive subject, solid mechanics contains unsystematic and complicated knowledge with many formulas and heavy calculation burden. Considering the teaching innovation in soil mechanics and cultivation of students’ innovation ability, the author made many researches from the perspectives of theories and experiments. Zhang Peng (2009) holds that teachers should focus on guiding students to understand key knowledge with the mentality of academic inquiry and help them master all details and limitations of certain knowledge. Also, the process of proposing and completing theories can be taught to cultivate the researching ability and spirit of students. Zhang Baihong (2006) proposed the adoption of the Matlab thermal analysis function for the calculation of unsaturated soil seepage targeting at the drawback of simulating two-side seepage field via the electric imitation method. Fei Kang (2011) taking the teaching of Terzaghi Ground Bearing Capacity Theory as an example, introduced the shape of failure plane in the ground in the form of group discussion, then let students inquiry the derivation of the calculation formula independently, and finally extended the theory so as to draw inferences. Other scholars (Er, 2011; McDowell, 2001; Qiang, 2012; Roberto, 2015; Wei, 2014; Xu, 2011; Zhi, 2011) also made relevant researches in terms of innovation in the teaching of soil mechanics theories and practice as well as comparison of teaching of soil mechanics at home and broad.
This paper, with teaching of the calculation of the active earth pressure of cohesive soil based on Rankine Earth Pressure Theory and on the judgment on the condition of earth’s limit equilibrium as the example,

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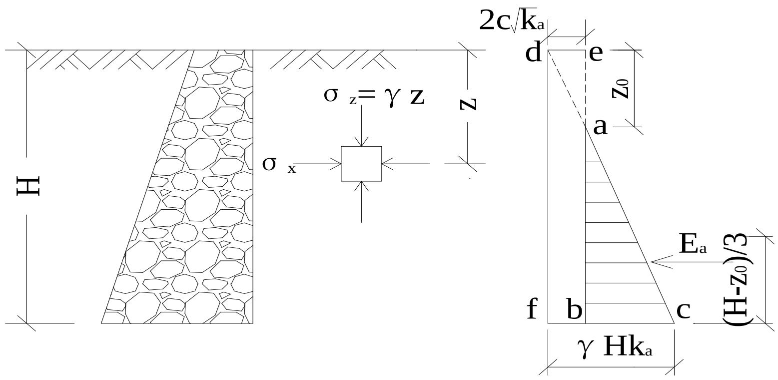
studied the teaching method of extending knowledge besides basic theories explanation to prioritize the enhancement of students' innovation ability and competence to analyze and solve practical problems through learned knowledge.

3. The example of innovation in the teaching of soil mechanics

3.1 The calculation of active earth pressure of cohesive soil based on Rankine Theory

The figure of calculation of active earth pressure of cohesive soil based on Rankine Theory in the textbook is shown as Figure 1(a). According to the relation between the maximum and minimum principal stress and the condition of limit equilibrium, the active earth pressure intensity of cohesive soil is calculated as $p_a = \gamma z K_a - 2c\sqrt{K_a}$, which refers to two parts of the intensity of cohesive soil, namely $\gamma z K_a$ and $-2c\sqrt{K_a}$. Owing to the fixed weight, cohesion and internal friction angle of homogeneous soil, γ and K_a are also constant values. In this sense, the first part of the pressure intensity is only related to the depth *z*, with positive correlation. However, the second part is constant, showing no correlation to *z*. The combined effect of the two parts of the pressure intensity is shown in Figure 1(b). On the top of the wall, *z*=0. So the combined value of the two parts of the pressure intensity is $-2c\sqrt{K_a}$, the negative one, meaning that the soil is pulled. In fact, even light tension force on the soil can lead to the separation of soil from the retaining wall. In Figure 1(b), the earth pressure intensity value is negative till the dept reaching z_0, so *ab* can be taken into consideration rather than *ae* for calculation of the overall earth pressure. And the overall earth pressure of cohesive soil equals to the area of △*abc*. In △*abc*, the length of *bc* can be got in line with Fig. 1(b) as $bc = \gamma H K_a - 2c\sqrt{K_a}$. Then the area of △*abc*, namely the overall earth pressure of cohesive soil is

$$E_a = \frac{1}{2}(H - z_0)(\gamma H K_a - 2c\sqrt{K_a}) \tag{1}$$



(a) Calculation of active earth pressure
(b) Cohesive soil

Figure 1: The distribution of active earth pressure intensity

Z_0 is the critical depth, with the value of the earth pressure intensity as zero. Then

$$z_0 = \frac{2c}{\gamma\sqrt{K_a}} \tag{2}$$

Apply formula (2) to formula (1), then

$$E_a = \frac{1}{2}\gamma H^2 K_a - 2cH\sqrt{K_a} + \frac{2c^2}{\gamma} \tag{3}$$

Formula (3) is often used in most textbooks (Chen, 2013; Cheng, 2013) for the calculation of active earth pressure of cohesive soil based on Rankine Theory. But this formula is not memory-friendly with so many parameters, and is different from the formula for the calculation of active earth pressure of cohesionless soil. Thus, students can be guided to watch the figure of distribution of the earth pressure of cohesive soil, leading to $\Delta abc \backsim \Delta dfc$. In line with the nature of similarity, $\frac{ab}{df} = \frac{bc}{fc}$ is obtained. Then with specific values given, $\frac{H - z_0}{H} = \frac{\gamma HK_a - 2c\sqrt{K_a}}{\gamma HK_a}$ is got, which results in $\gamma HK_a - 2c\sqrt{K_a} = \gamma K_a(H - z_0)$. Apply this formula to Formula (1), and a new formula can be obtained as $E_a = \frac{1}{2}\gamma(H - z_0)^2 K_a$. It is very similar to the formula of the active earth pressure of cohesionless soil $E_a = \frac{1}{2}\gamma H^2 K_a$, and thus memory-friendly for students.

3.2 The method of judging the condition of the soil limit equilibrium

3.2.1 The judgment in the textbook

The condition of the soil limit equilibrium is widely used in soil mechanics, such as judgment on stability of soil body, calculation of the critical edge pressure, plastic load and ultimate load of the foundation and the calculation of earth pressure based on Rankine theory. In the textbook, the following two methods are usually introduced to judge the condition of soil limit equilibrium. The first is to figure out σ_{1f}, in the condition of the soil limit equilibrium via σ_3, and then compare the value of σ_1 and σ_{1f}(Fig.2). If $\sigma_1 = \sigma_{1f}$,, the soil body is in the state of limit equilibrium; if $\sigma_1 < \sigma_{1f}$, Mohr circle determined by σ_1 and σ_3 is below Circle Ⅰ and separates from the intensity envelope curve, meaning the soil is in the elastic state; if $\sigma_1 > \sigma_{1f}$, Mohr circle determined by σ_1 and σ_3 is above Circle I and inter-crosses the intensity envelope curve, meaning the soil is in the state of failure. And the second method is to figure out σ_{3f} in the condition of the soil limit equilibrium via σ_1, and then compare the value of σ_3 and σ_{3f}(Fig.3). If $\sigma_3 = \sigma_{3f}$, the soil body is in the state of limit equilibrium; if $\sigma_3 < \sigma_{3f}$, Mohr circle determined by σ_1 and σ_3 is above Circle Ⅰ and inter-crosses the intensity envelope curve, meaning the soil is in the state of failure. And if $\sigma_3 > \sigma_{3f}$, Mohr circle determined by σ_1 and σ_3 is below Circle Ⅰ and separates from the intensity envelope curve, meaning the soil is in the elastic state.

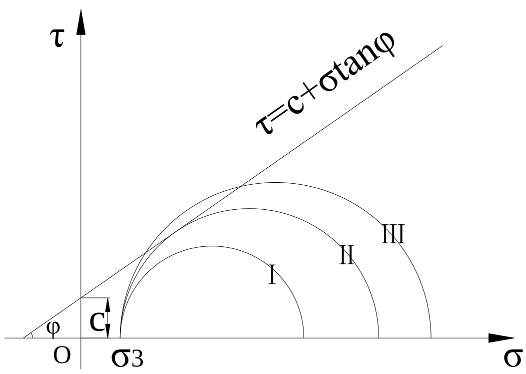


Figure 2: Judgment on the soil state by comparison of σ_1 and σ_{1f}

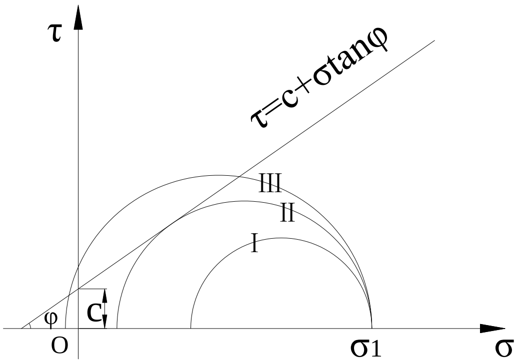


Figure 3: Judgment on the soil state by comparison of σ_3 and σ_{3f}

Students are guided to actively think over when watching the relation between Mohr circle and the intensity envelope curve, leading to the conclusion that the relation can reflect the soil state. Through such guidance and thinking, the method of judging the soil limit equilibrium state is finally put forward, and meanwhile students' ability to analyze and solve problems are raised.

3.2.2 The new method of judgment

The first new method: according to the distance from the Mohr circle center (($\sigma_+\sigma_3$)/2,0) to the line of shear strength $\tau = c + \sigma \tan\varphi$, then compare the distance $d = \dfrac{\left|\dfrac{\sigma_1+\sigma_3}{2} - c\right|}{\sqrt{1^1 + \tan^2\varphi}}$ with the radius of Mohr circle r=(σ-σ3)/2 (Fig. 4.). If r<d, that means that the line of shear strength I intersect the Mohr circle and the soil is in damage state. If r=d, that means that the line of shear strength II tangent to the Mohr circle and the soil is under the limit equilibrium condition. If r>d, that means that the line of shear strength Ⅲ depart the Mohr circle and the soil is under elastic condition.

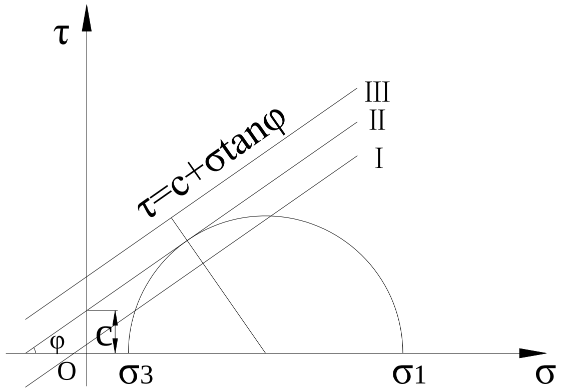


Figure 4: Compare the r with d, judge the condition of the soil

The second new method: calculate the sine of friction angle when the soil soil is under the limit equilibrium condition, the sinφ_f=(σ-σ_3))/($\sigma_+\sigma_3$+2c·cotφ), then compare the sinφ with sinφ_f. If sinφ_f<sinφ, that means that the soil is under elastic condition. If sinφ_f=sinφ, that means that the soil is under the limit equilibrium condition. If sinφ_f>sinφ, that means that the soil is in damage state.

The third new method: calculate the cohesion c_f when the soil soil is under the limit equilibrium condition, the c_f=(σ_1(1-sinφ)-σ_3(1+sinφ))/(2cotφ), compare the c_f with c. If c_f<c, that means that the soil is under elastic condition. If c_f=c, that means that the soil is under the limit equilibrium condition. If c_f>c, that means that the soil is in damage state.

3.2.3 Examples

A cohesive, known for its shear strength index **c**=10*kPa*, φ=30°. The triaxial compression experiments on the soil sample and the stress is σ_1=300*kPa* and σ_3=100*kPa*. Determine the condition of the soil.

The first method:

$$\sigma_{1f} = \sigma_3 \tan^2(45^\circ + \frac{\phi}{2}) + 2c \cdot \tan(45^\circ + \frac{\phi}{2})$$

$$= 100 \times \tan^2(45^\circ + \frac{30^\circ}{2}) + 2 \times 10 \times \tan(45^\circ + \frac{30^\circ}{2}) = 334.6kPa$$

σ_3>σ_{3f}, this shows that the soil sample is in elastic stage.

The second method:

$$\sigma_{3f} = \sigma_3 \tan^2(45^\circ - \frac{\phi}{2}) - 2c \cdot \tan(45^\circ - \frac{\phi}{2})$$

$$= 300 \times \tan^2(45^\circ - \frac{30^\circ}{2}) - 2 \times 10 \times \tan(45^\circ - \frac{30^\circ}{2}) = 88.45kPa$$

$\sigma_1 < \sigma_{1f}$, this shows that the soil sample is in elastic stage.
The third method:
According to the straight-line distance from the center of the Mohr circle to the line of shear strength.
The line of shear strength:

$$\tau = c + \sigma \cdot \tan\varphi = 10 + \sigma \cdot \tan 30^\circ = 10 + \frac{\sqrt{3}}{3}\sigma$$

Mohr circle center coordinates: (200, 0)
The distance of Mohr circle center to the line of shear strength d:

$$d = \frac{\left|\frac{\sqrt{3}}{3} \times 200 - 0 + 10\right|}{\sqrt{(\frac{\sqrt{3}}{3})^2 + (-1)^2}} = 108.6$$

The radius of Mohr circle r:

$$r = \frac{\sigma_1 - \sigma_3}{2} = \frac{300 - 100}{2} = 100$$

$d>r$, this indicates that the Mohr circle depart the shear strength line and the soil is under elastic condition.
The fourth method:

$$\sin\varphi_f = \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3 + 2c \cdot \cot\varphi} = \frac{300 - 100}{300 + 100 + 2 \times 10 \times \cot 30^\circ} = 0.46 < \sin 30^\circ = 0.5$$

This indicates that he soil isn't damage.
The fifth method: compare the c_f with c
When the soil is in limit equilibrium condition, then

$$c_f = \frac{\sigma_1(1 - \sin\varphi) - \sigma_3(1 + \sin\varphi)}{2\cot\varphi} = \frac{300 \times (1 - \sin 30^\circ) - 100 \times (1 + \sin 30^\circ)}{2 \times \cot 30^\circ} = 0 < c = 10$$

This indicates that he soil isn't damage.

4. Conclusion

This paper, taking the teaching of the calculation of the active earth pressure of cohesive soil based on Rankine Earth Pressure Theory and of the judgment on the condition of earth's limit equilibrium as an example, analyzed and deduced the calculation formula of the overall active earth soil pressure of cohesive soil based on Rankine Theory by combining the nature of similar triangles. In this way, the memory-friendly calculation formula for students was obtained to replace the formula that is not memory-friendly in the textbook. And the soil limit equilibrium state could be analyzed through the formula of the distance between beeline and dot as well as the number of solutions of equation. All these were newly proposed based on students' knowledge structure and the textbook, which has cultivated and enhanced students' innovation ability.

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