PriMera Scientific Engineering
Volume 4 Issue 1 January 2024
DOI: 10.56831/PSEN-04-099
ISSN: 2834-2550

PriMera Scientific Publications

Equation and General Law of the State of Gas-Containing Liquids Located in the Pore of Multiphase Clay Soils

Type: Research Article
Received: November 28, 2023
Published: December 19, 2023

Citation:
Togtokh N. "Equation and General Law of the State of Gas-Containing Liquids Located in the Pore of Multiphase Clay Soils". PriMera Scientific Engineering 4.1 (2024): 25-32.

Togtokh N*

Doctor (Ph.D), Consultant Engineer, Ulaanbaatar, Mongolia

***Corresponding Author:** Togtokh N, Doctor (Ph.D), Consultant Engineer, Ulaanbaatar, Mongolia.

Abstract

The newly discovered general law on the compressibility of gas-containing fluid is used to calculate the density of multiphase clayey soil in a closed system under high pressure in the field of construction, taking into account the parameters of water saturation and dissolution of gases containing in thick layers of clayey soils of the foundations of high-rise buildings, the clay core of hydraulic dams and the environment of underground structures will allow you to perform engineering calculations of the foundations of buildings and structures with high accuracy.

Keywords: foundation soil; pore pressure; compressibility coefficient; Henry's law; Pauson's law

Introduction

Assuming that the rate of construction of the building is slow enough so as not to have a dynamic effect on the compaction of the soil, then the engineering calculation of the soil under the foundation at each stage of construction can be considered as the movement of the soil ending in an equilibrium state, and the final settlement value can be determined using the relationship between stress and deformation, and thus there is a condition for the application of deformation theory [1-3].

When constructing the foundation of a building and the core of a hydraulic sheet in multiphase clay soil, with a filtration coefficient of less than Kf<10...8 cm/sec, the consolidation compaction is calculated as in a closed system [4, 5].

In this case, under the action of an external load Pw from the building, the trapped gases and a mixture of gas-containing water located in the closed pore system of the soil mass undergo a change in volume or are compressed. In this process, the dependence of pressure and volume is related by the compressibility coefficient according to Hooke's law [6, 7].

However, if the soil water saturation coefficient is J_W=1, water in its natural state or under atmospheric pressure is water with a certain amount of gases in its composition. Therefore, according to the interpretation of Prof. N.A. Tsytovich [8] "gas-containing water found in the pores of clay soil has the compressibility ability of no less than the entire soil mass system." It then becomes necessary to reconsider the theoretical rationale, which is still used, that the compaction or settlement of a water-saturated soil is equal to the volume of water squeezed out of the pore space of the clay soil.

By the way, in 1938, Professor G.E. Pokrovsky [9] discovered through laboratory research that when pore water was not squeezed out, that is, water-saturated clay soil with a water saturation coefficient value of J_W=1 can undergo significant compressibility. He reported on his discovery at the All-Union Scientific and Technical Synfosium, unfortunately leading scientists did not acknowledge it, making an explanation that the allegedly discovered patterns were manifested in the results of the dependence of the granulometric composition of the soil, and also on the inaccuracy of experimental research.

Also in 1971-1972, the head of the department of the Leningrad Civil Engineering Institute, prof. B.I. Dalmatov and Nguyen Van Quang [10] used laboratory test curves to show that water-saturated clay soil is deformed in the absence of squeezing soil water out of the pore space.

Methods and Materials

Shavarlag st. Khorsniy nuh syvlegiin oron zayg ezelsen hiitey shingeniy gadnyn achaallaas үүseh daralt ba ezlekhүүniy өөrchloltiyn deformationn khareltsan hamaarlyg usand uusalt, khanaltyn parameter үdtey holbon ilerkhiylne gedeg ny uul hiitey shingeniy daraltyn doorkh mechanic tolov baydlyn tagshitgeliyg todorkhoilno gesen khereg bilee.

Ene nөkhtsөld hiitey shingeniy daralt ba ezlekhүүniy өөarchlөltiyg holbogdoh parameterүүdtei ni holboson toolөv baidlyn tagshitgeliyn baruun gar talyn todorkhoyguy helberiyn funktsiig neeh oroldlo hiye.

Having expressed the relationship between the change in pressure and volume caused by the external load of the gas liquid occupying the pore space of the clay soil, depending on the water solubility and saturation parameters, lies in determining the equation of the mechanical state of the gas liquid under pressure. In this regard, let's try to find a function of unknown form on the right side of the equation of state, which relates changes in pressure and volume of a gas-containing liquid with the corresponding parameters.

$$\theta_w = \frac{\Delta V}{V_w} = f(P_w, L_i), \qquad (1)$$

where

θ_w - is the relative change or volumetric deformation corresponding to the change in external force in the space occupied by the gas-containing liquid;
ΔV - change in volume corresponding to a change in the external force of the gas-containing liquid;
Li - fluid parameters, where i=1,2,3...n;
Pw - is the external pressure on the gas-containing liquid occupying the pore space of the soil;
Vw - is the total volume of gas-containing liquid;
f - the sought function;

To reveal this unknown function, the mechanical behavior under pressure of trapped gas or gas-containing liquid occupying the pore space of a multiphase clay soil is schematically visualized in Figure 1 [5].

The diagram shows that the total volume of soil pore space or the volume of gas-containing liquid at J_W=1:

$$V_w = V_x + V_y + V_{yx}, \qquad (2)$$

where V_x is the volume of trapped gas, V_y is the volume of water, V_{yx} is the volume of gas dissolved in water.

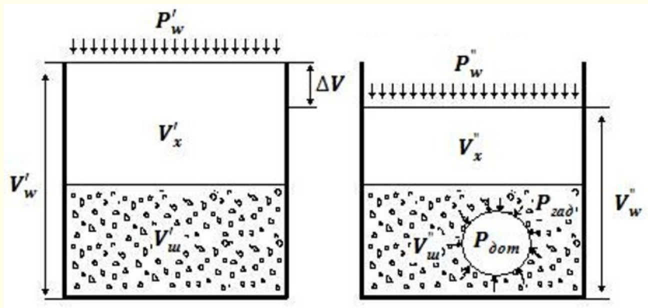

Figure 1: Diagram of compressibility of a gas-containing liquid.

Volume of gaseous liquid:

$$V_ш = V_y + V_{yx}, \qquad (3)$$

where V_x - is the volume of trapped gases, V_y - is the volume of water, V_{yx} - is the volume of gases dissolved in water.

$$V_{yx} = \sum_{i=1}^{n} Vxbi\ , \qquad (4)$$

where *Vxbi* - is the volume of gas bubbles of i-th quantities.

When the pressure changes from P'_ω to P''_ω the volume of pinched gas ΔV changes, then the volume of pinched gases Vx changes according to the Boyle-Marriott law under pressure P''_ω- P'_ω =ΔP. Gas bubbles satisfy the following two equilibrium conditions in volume and height. It includes:

Conditions for equilibrium of the volume of a gas bubble in gas containing water. The internal and external pressures of the gas bubble must be equal:

$$P_{гад} = P_{дот}, \qquad (5)$$

where $P_{гад} = P_{at} + P_\omega + P_k$ or $P_{дот} = F(T) + n \cdot \frac{RT}{V_{xb}}$

Assuming equilibrium:

$$P_{at} + P_\omega + P_k = (T) + n \cdot \frac{RT}{V_{xb}}\ , \qquad (6)$$

where
P_{at} - is atmospheric pressure;
P_ω - pressure acting on the gas-containing liquid;
P_k - capillary pressure;
$F(T)$-is the internal pressure of the bubble, which arises depending on the temperature;
n - is the number of molecules inside the bubble;
R - gas constant;
T - absolute temperature.

According to equilibrium conditions, the volume of bubbles contained in the water will not change.

Condition for equilibrium of the height (buoyancy) of gas bubbles in gas-containing water. A gas bubble does not necessarily float on the surface of water if the following equilibrium conditions are met.

$$Y_y \cdot g \cdot V_{xb} < F, \qquad (7)$$

where
Y_y - is the specific gravity of water;
g - free fall acceleration;
V_{xb} - volume of gas bubbles;
F - is the adhesion force of the liquid (water).

According to the condition for the balance of volumes of gas bubbles in water, the last term on the right side of equation (6) $n \cdot \frac{RT}{V_{xb}}$ increases the number of molecules by increasing the internal pressure P_{dot} of the gas bubble and balancing the external pressure at $P_w = P_{gad}$, the volume balance condition is satisfied.

Research Methods

For the conditions of closed systems Vx > 0 and Vx = 0, the laws converge and idealize. Under closed system conditions Vx > 0, the external pressure under the influence of Pw undergoes the following changes. It includes:

- The trapped gas changes its volume in accordance with the Boiler-Marriott law;
- Gas, which has penetrated into gas-containing water according to Henry's law, increases the number of gas molecules in the bubbles and the density, as a result of which the density of the trapped gases becomes equal;
- Since the equilibrium conditions for the volume and buoyancy of gas bubbles are maintained, the volume of water containing gas is constant;

However, under the conditions of a closed system at Vx = 0, the action of Henry's law ceases; as the external pressure Pw increases, the volume of gas-containing water Vyx changes and is deformed according to Poisson's law.

According to the law of conservation of mass in a closed system, shown in Figure 1, the parameters corresponding to two different values of external Pw - the pressure of the gas-containing liquid, were noted as follows:

where:
P'_ω - at this pressure;
V'_x - volume of trapped gas;
p'_x - density of trapped gas;
m'_x - gas mass;
$V'_Ш$ - volume of liquid;
$\rho'_Ш$ - volume of liquid;
$m'_Ш$ - liquid mass;

$$m'_0 = m'_Ш + \rho'_x V'_x \; ; \qquad (8)$$

$$V'_\omega = V'_x + V'_0; \qquad (9)$$

Under pressure P''_ω:
X''_x - volume of trapped gas;
ρ''_x - density of trapped gas;
m''_x - mass of trapped gas;
$V''_Ш$ - volume of liquid;

$\rho''_ш$ - liquid density;

$m''_ш$ - mass of liquid.

$$m''_0 = m''_ш + \rho''_x V''_x\,, \qquad (10)$$

$$V''_\omega = V''_x + V''_0, \qquad (11)$$

For a closed system, the mass of the gas-containing liquid mo is constant. However, the change in the volume of the gas-containing liquid, corresponding to two different values of external pressure, is equal to the change in the volume of the trapped gas according to equilibrium conditions 8 and 10, therefore it is equal to the difference in the density of the trapped gas and is multiplied by its volume and added to the difference in the masses of water with gas, which is expressed as follows.

$m_0 = m'_0 = m''_0 = m'_ш + \rho'_x V'_x = m''_ш + \rho''_x \cdot V''_x$ from the equilibrium condition:

$m'_ш = m''_ш + V'_x(\rho'_x - \rho''_x = \Delta V \rho''_x$ based on this

$$\Delta V = \frac{m''_ш - m'_ш}{\rho''_x} + V_x \frac{\rho''_x - \rho'_x}{\rho''_x}\,, \qquad (12)$$

Research Results

For a gas-containing liquid in a closed system, consider the difference in the mass of water of gaseous composition corresponding to two different pressures under the conditions Vx > 0 on both sides. On the one hand, the difference in the mass of water with a gas composition, corresponding to two different external pressures, is directly proportional to the pressure difference:

$$m''_ш - m'_ш = \mathrm{C} \cdot V_ш (P''_W - P'_W) \qquad (13)$$

where C - is the pressure difference coefficient.

This equation actually has the same content as Henry's law, so the coefficient C is the Henry coefficient. This is due to the fact that it is directly related to the change in the mass of the dissolved gas, corresponding to the change in the external pressure on the gas-containing liquid, or to the change in the number of molecules in the gas bubbles found in water.

On the other hand, under the condition Vx > 0, the corresponding difference in the mass of water in gas-containing water, corresponding to the external pressure, is expressed by the condition of the difference in the densities of the gas dissolved in it, equal to the product of a constant volume:

$$m'_ш = V_y \cdot \rho_y + V'_{yx} \cdot \rho'_{yx}; \qquad (14)$$

$$m''_ш = V_y \cdot \rho_y + V''_{yx} \cdot \rho''_{yx}; \qquad (15)$$

$$m''_ш - m'_ш = V''_{yx} \cdot \rho''_{yx} - V'_{yx} \cdot \rho'_{yx}; \qquad (16)$$

$$V'_{yx} = V''_{yx} = V_{yx}\,, \quad \text{then} \qquad (17)$$

$$m''_ш - m'_ш = V_{yx}(\rho''_w - \rho'_w); \qquad (18)$$

According to the Boyle-Mariotte law, the dependence of the density of the trapped gas and pressure is expressed by the following relation:

$$\frac{P''_W}{\rho''_x} = \frac{P'_W}{\rho'_x}\,, \qquad (19)$$

This expression easily translates to the following formula.

$$\frac{P''_w - P'_w}{\rho''_x - \rho'_x} = \frac{P'_w}{\rho'_x} = \beta, \text{ hence} \qquad (20)$$

$$P''_w - P'_w = \beta(\rho''_x - \rho'_x); \qquad (21)$$

$$\frac{1}{\beta}(P''_w - P'_w) = \rho''_x - \rho'_x; \qquad (22)$$

If we substitute these expressions into (19) and compare them with (15), the above mentioned coefficients are determined:

$$C \cdot V_{ш}(P''_w - P'_w) = V_{yx}(\rho''_{yx} - \rho'_{yx}) = V_{yx} \cdot \frac{1}{\beta}(P''_w - P'_w); \qquad (23)$$

$$C\beta V_{ш} = V_{yx}; \qquad (24)$$

$$C\beta = \frac{V_{yx}}{V_{ш}} = \frac{\mu}{1+\mu}; \qquad (25)$$

Here, by substituting $V_{ш} = V_y + V_{yx}$ into the denominator and dividing the divisor by Vy, you can easily obtain the unitary value of the coefficients. $\mu = V_{yx}/V_y$ coefficient of gas dissolution in water under pressure. Substituting equation (20) into equation (12), which expresses the change in volume of a gas-containing liquid, gives the following equation (26).

$$\Delta V = (V'_x + C\beta \cdot V_{ш}) \cdot \frac{P''_w - P'_w}{P''_w}, \qquad (26)$$

where $V_x = V_w - V_{ш}$;

This equation represents the value of the change in volume of a gas-containing liquid corresponding to a change in external pressure,

- The first term on the right side represents the change in the volume of trapped gas at a constant temperature according to the Boiler-Marriott law;
- The second term is also the fact that under pressure gas molecules penetrate into water according to Henry's law;

An adiabatic change representing the transition between two phases, "pinched gas and water with a mixture of gases", and considering these mechanical operations as analogous thermodynamic processes is an isothermal-adiabatic change.

If we replace (9) and (26) or substitute pressure changes Pw into (27) and divide both sides by V'_w,, we obtain a general dependence of the relative change in the volume of the gas-containing liquid, corresponding to the change in external pressure on the gas-containing liquid and its parameters. The equation of mechanical state under pressure is obtained in the following form.

$$\frac{\Delta V}{V'_w} = \left(1 - \frac{V_{ш}}{V'_w} + \frac{\mu}{1+\mu} \cdot \frac{V_{ш}}{V'_w}\right) \cdot \frac{P''_w - P'_w}{P''_w}, \qquad (27)$$

If $\frac{V_{ш}}{V'_w}$ is compared with the total volume of gas-containing liquid with the water saturation coefficient Jw, and also $\frac{\Delta V}{V'_w}$ or the relative change in the volume of gas-containing liquid or volumetric deformation is denoted by θw, it will have the following form.

$$\theta_w = \frac{\Delta V}{V'_w} = \left(1 - J_w + \frac{\mu}{1+\mu} \cdot J_w\right) \frac{P''_w - P'_w}{P''_w}, \qquad (28)$$

It expresses the equation of state of a liquid under external pressure under quasi-static conditions, and on the right side of equation (1), the function f is determined, marked in indefinite form. Hence, the change in volume and compressibility of a gas-containing liquid under external pressure can be easily expressed using Hooke's law.

$$-\frac{1}{V'_w} \cdot \frac{\Delta V}{\Delta P} = \left(1 - J_w + \frac{\mu}{1+\mu} \cdot J_w\right) \frac{1}{P''_w} = -a_w; \qquad (29)$$

According to this expression, although Jw = 1, in water at atmospheric pressure or in its natural state there is a certain amount of gas composition, and if Pat = 1, then its compressibility coefficient will be equal to $a_w \frac{\mu}{1+\mu}$. According to N.A. Tsytovich's classification, it is theoretically expressed that water with this gas combination in the pores of water-saturated soil can be compressed no less than rock systems. It has also been established that the compactability of water-saturated soil is not equal to the volume of water squeezed out of the pore space of water-saturated soil, as has been provided so far.

If we accept the boundary condition for the limit transition ΔP → 0 from equation (27), it changes to a differential equation of the following form:

$$\frac{1}{V} \cdot \frac{dV}{dP} = \left(1 - J_w + \frac{\mu}{1+\mu} \cdot J_w\right) \cdot \frac{1}{P}, \qquad (30)$$

Under the condition P=Pat, a particular solution of this equation, integrated by the method of differentiating variables under the boundary condition V=Vo in accordance with P=Pat, is a general law relating the change in pressure and volume of the gas-containing liquid containing in its pores with the parameters of water saturation and dissolution in a closed system of multiphase clay soil is determined by the following formula [5, 7, 11].

$$V = V_0 \left(\frac{P_{at}}{P_w}\right)^{1-J_w+\frac{\mu}{1+\mu}J_w}, \qquad (31)$$

In this general law, the coefficient under the condition of water saturation is Jw = 0, or when the pore space of the soil is occupied only by trapped gases, then the change in pressure and volume occurs according to the Boiler-Marriott law.

$$V = V_0 \frac{P_{at}}{P_w} \quad \text{or} \quad VP_w = V_o P_{at}$$ - this is Boyle Marriott's law.

If the coefficient of water saturation changes to Jw = 1 and the volume of trapped gas Vx = 0, then the pore space of the soil will be occupied only by gas-containing water, then the general law is the following Poisson's law.

$$V = V_0 \left(\frac{P_{at}}{P_w}\right)^{\frac{\mu}{1+\mu}} \quad \text{– or} \quad \mathbf{V^{1/\gamma}P_w = V_o^{1/\gamma}P_{at}}$$ – this is Poisson's law.

$$where \quad \gamma = \frac{\mu}{1+\mu}$$

lso, under given conditions, the effect of Henry's law is limited if the penetration of gas molecules into gas-containing water under pressure is limited. On the other hand, gas bubbles contained in water under the influence of external pressure undergo a change in volume according to Poisson's law.

Graphs of the general law (31) are plotted and shown in Figures 1, 2 and 3 [5]. As can be seen from graph 1, the relationship between pressure and volume change or volumetric deformation of a gas-containing liquid is indeed nonlinear, and if we assume it to be linear, then the solution error will exceed the permissible limit.

As shown in the graph, when Jw = 0.9, the relationship between pressure and volume change again diverges by an integer number between linear and nonlinear. Also, as shown in graph 3, it is not always true that the water saturation coefficient does not depend on pressure.

Questions for Discussion

The newly discovered general law of gas-containing liquid (31) is used to calculate the density of multiphase clay soil in a closed system under high pressure in the field of construction, taking into account the parameters of water saturation and dissolution of gases containing in thick layers of clay soils, the foundations of high-rise buildings, the clay core of hydraulic dams and the underground environment structures will make it possible to carry out engineering calculations of the foundations of buildings and structures with high accuracy.

This general law expresses the pattern of changes in its volume under external pressure in a closed pore space with a mixture of gas and gas, associated with the parameters of solubility and saturation in water. When pressure and volume change according to this pattern, Boiler-Marriott's law, Henry's law and Poisson's law act together and separately.

Prof. G.E. Pokrovsky in 1938, prof. B.I. Dalmatov Nguyen Van Quang in 1971...1972, through laboratory experiments, "Clay soils saturated with water underwent volumetric deformation in a closed system. Also, the explanation of the theoretical basis of the phenomenon of "nonlinear relationship between pressure and deformation" is expressed only by this general law (31).

The general law explains the relationship between pressure and volume of any mixture of gas and liquid, often found in nature, depending on their parameters. This may be a law of nature. The application is then not limited to the construction industry.

Academician S. Batmunkh, academician Ch. Avday, academician S. Sodnomdorzh, doctor. prof. Zh. Tyumen and others wrote in page 105 of volume 101 of the Science of Mongolia series "The author discovered a general law relating the pressure and volume of gas-containing liquid in the pores of multiphase clay soil under the foundations of buildings, taking into account the parameters of its water saturation. They concluded: In fact, this is a scientific discovery."

Conclusions

1. Pore fluid in multiphase clay soils under pressure is compressed not only isothermically according to the Boyle-Mariotte law, as previously thought, but according to complex patterns, that is, according to Isothermo-Adiabatic or according to the Boyle-Mariotte, Henry and Poisson laws.
2. The compressibility of the pore fluid cannot be neglected even at Jw = 1, until now it was believed that in this case the value of water saturation is the compressibility coefficient aw = 0, since with such a value of water saturation of an averagely compressible soil / according to the classification of Prof. N.A. Tsytovich / compressibility pore fluid is no less than the compressibility of the soil skeleton itself.

References

1. Lamb W. "Pore pressure in a foundation clay". J.soil of mech. ASCE 88.2 (1962).
2. Papaleksi ND. Physics course 1.2 (1948).
3. Ter - Martirosyan ZG. "Forecast of subsidence of the earth's surface during pumping of groundwater". Problems of geomechanics 6 (1973).
4. Leibenzon LS. "Movement of natural liquids and gases in porous media". Gostekhizdat (1948).
5. Togtokh N. "Study of pore pressure in multiphase clayey soil under complex stress state taking into account the time factor". Abstract. diss... Ph.D (1975): 26C.
6. Hamilton LW. "The effect of internal hydrostatic pressure on shearing strengths of soils". Proc. ASTM vol.39.1939.
7. Togtokh N. "On the theoretical problems of compaction of clayey soils". MSU. Collection of scientific papers 47 (1974).
8. Tsytovich NA. Soil mechanics (1963).
9. Pokrovsky GI. "On the physical principles of calculating soil deformations". Mat. All-Union conference on foundations and foundations. Gosstroyzdat (1939).
10. Dalmatov BI and Ngun Van Quang. Study of the deformability of gas-containing clay soils (1972).
11. Togtokh N. "Equation of state of compressible fluids in multiphase physical soils". MSU. Collection of scientific papers 4.54 (1975).