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Olena Mykhailovska ✉; Vadim Chernikov



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# Dynamic Compaction of Mixtures of Soil and Waste from the Oil and Gas Industry

Olena Mykhailovska[1,a)], Vadim Chernikov[1,b)]

[1]*National University "Yuri Kondratyuk Poltava Polytechnic", Pershotravnevyj Ave. 24, 36011 Poltava, Ukraine*

[a)] Corresponding author: helena_2005@ukr.net
[b)] chernikov.vadim123@gmail.com

**Abstract.** The article analyzes the behavior of clay soil during compaction. It is confirmed that in the mixture of clay soil and drilling mud during dynamic compaction, a structure different from the natural one is formed and the aggregates are destroyed. Therefore, the mixture of clay soil with drilling mud 90:10 at optimum humidity can be characterized by a dispersion structure. The article determines the increase of the average modulus of deformation of the mixture of soil with drilling mud at the ratio of soil and drilling mud 90:10 by an amount close to 4%. It is determined that the addition of 10% drilling mud to clay soil during the construction of foundations increases the strength characteristics of the soil.

## INTRODUCTION

The formation of embankments and soil cushions requires a large amount of soil, which is usually taken from special quarries. The construction of quarries leads to the loss of fertile land, which contradicts the solution of environmental issues in specific areas. This raises the question of complete or partial replacement of embankment soils with other materials. However, large areas of fertile land in Ukraine are being destroyed by barn-sludge storage facilities for storing drilling mud. It would be advisable to find a way to use such waste for the construction of earthworks. In this way, the environmental problems of many industrial regions can be effectively addressed.

To ensure long-term strength and improve construction properties, it is desirable to give drilling waste the characteristics of cohesive soil. This can be solved by creating a mixture of drilling mud and a metered amount of local clay soil.

The works of domestic and foreign researchers have developed the basics of the theory of compaction of three-phase clay soils and methods for evaluating the efficiency of various compactors. However, a number of issues related to soil compaction have not been sufficiently addressed. Regularities of compaction of soils and their mixtures in the laboratory to date is described by the "standard method" proposed in the early twentieth century [1]. For a long time, attention was paid to the study of the theory of soil compaction V.B. Shvets (1958), V.G. Khilobok, V.I. Kovalenko [2].

Requirements for soil compaction are always reduced to the observance of optimal soil moisture and to achieve close to the maximum density. To determine the optimal moisture $W_{opt}$ and the maximum density $\rho_{dmax}$ most often used impact action on the ground. The specific energy of the seal varies significantly and varies from $5.9\cdot10^{-1}$ J/cm$^3$ in the method of the American Association of Civil Servants (AACS) to $27\cdot10^{-1}$ J/cm$^3$.

Also laboratory compaction of soil was made by cyclic static loadings, thus modeling influence of compacting mechanisms on soil in production conditions (Klebanyuk D.N., Poita P.S., Shvedovsky P.V. (2013) [3]) Dynamic consolidation (V.I. Kovalenko (2002) [4]), vibration compaction (Minaev O.P. (2008) [5]) were applied.

For artificial compaction of soils, gravel and crushed stone foundations in the construction of the subsoil foundations, equipment was used that perform compaction by rolling, compaction and vibration. When compacted, soil or material particles are displaced and stacked more compactly due to the displacement of the liquid and



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gaseous phases. This leads to a decrease in the volume of soil (material) and the formation of a denser and stronger structure.

After stiffening, the seal occurs under the static action of the mass of the roller. When ramming, soil compaction is achieved by the dynamic influence of falling cargo. Rolling is carried out by trailer, semi-trailer and self-propelled rollers with metal working bodies of various form and wheels with pneumatic tires. Also known are other laboratory methods that explain the processes of rocking by different rollers (Averyanov V.M. (2016) [6]).

The purpose of the article is to study the compaction and strength characteristics of a mixture of loess loam with drilling mud in a ratio of 90:10 for the use of this material in the national economy.

## METHODOLOGY AND RESEARCH

Currently in Ukraine, there are environmental problems in the oil and gas regions. When drilling wells, a significant amount of waste is generated, which must be disposed of. For the collection and accumulation of this type of waste, sludge barns of considerable size are created. Drilling mud contains heavy metals, a small amount of petroleum products, synthetic surfactants, carboxymethyl cellulose, synthetic organic substances and more.

"Solidification" is an effective technology for utilization of drilling rigs. According to this method, the purified drilling mud is mixed with special sorbents and cement. The sorbent binds compounds that, after the addition of cement, turn into a form that is insoluble in all weather conditions. Therefore, the thus neutralized product is used in the manufacture of building materials [7]. There is a chemical method of disposal using phosphogypsum. [8].

The authors propose to use drilling waste for the construction of embankments and foundations in railway construction. Requirements for soil compaction are always reduced to compliance with some soil moisture during compaction and to achieve a certain density. Establishment of values of these parameters is usually made on the basis of laboratory experiments on consolidation. As a result of these researches find optimum humidity of $W_{opt}$ - that humidity at which the maximum density of dry soil is reached.

It is known that there are two types of natural structure formation of clay soils: one - salt, in which dispersed particles are deposited from the colloidal solution. At the moment of deposition of these particles between adjacent particles, electrical repulsive forces act. This allows the particles to slide one by one, taking the position corresponding to the best packaging. The location of the particles will be close to parallel.

Another type of structure formation is non-salt, obtained as a result of flocculation (formation of aggregates) in a colloidal solution. In this case, during the deposition of the units, mainly electric gravity acts, as a result of which the individual units are glued together. The orientation of the particles is chaotic. The location of adjacent particles relative to each other is close to perpendicular. That is, the negative poles of the particles are in contact with the positive ones. In the first case, the structure is called dispersion and the orientation of the particles is parallel. In the second case, the structure is called flocculation and the orientation of the particles is chaotic.

In the flocculation structure of the assembly, the filtration and mechanical properties of the soil are determined by the nature and strength of the bonds between the units, rather than the location of the particles in the unit. At a dispersion arrangement the degree of orientation of soil particles acquires great value. The microstructure of clay soil can be assessed by direct methods in the relative value of certain indicators that depend on the degree of orientation of the particles, or by microscopic studies [6].

A comprehensive study of the microstructures of different clay soils has shown that in the natural state the vast majority of clay soils are characterized by a flocculation structure [6]. In the process of compaction of clay soil by means of dynamic soil compaction in the device MDU-1, it forms a structure different from the natural one. The aggregates are destroyed, the inter-aggregate porosity decreases and a more homogeneous soil mass is created. The array of soil mixture, depending on the humidity, the method of its compaction and the amount of energy spent on compaction can be characterized by a dispersion structure.

With the same method of soil compaction with different humidity, the transformation of soil structure from flocculation to dispersion is accompanied by the achievement of the maximum density of dry soil for the adopted method of compaction and its subsequent reduction. At the same time in the soil there are about 10% of the pores which are not filled with water. The water saturation coefficient of the soil is 0.9. [8].

Numerous observations have shown that in clay soils compacted at sub-optimal humidity, most particles have a chaotic arrangement. When soils with higher humidity are compacted, soil particles tend to a parallel location like Fig. 1.

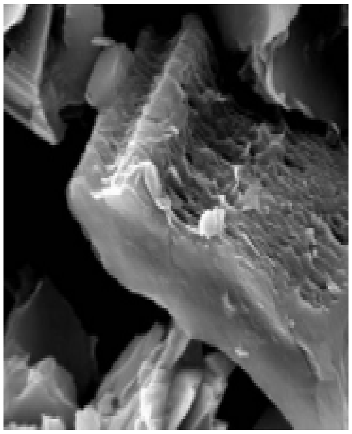

**FIGURE 1.** General view of the electron microscopic image of clay soil [9]

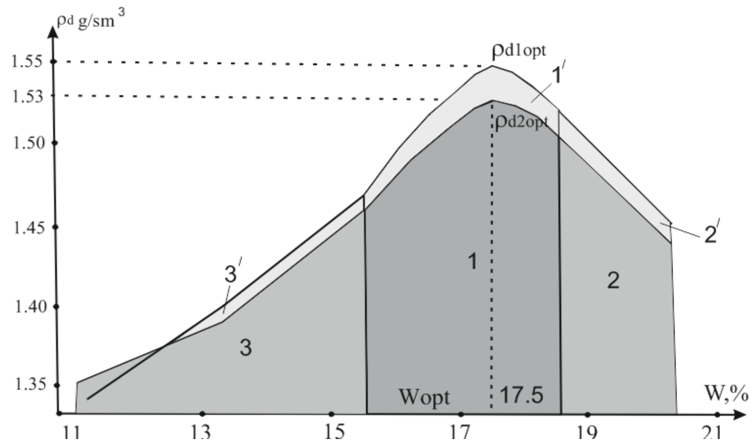


**FIGURE 2.** Dependence of the state of highly dispersed soil on its moisture and soil skeleton density: 1, 1/ - zone of elastic-plastic properties with loose water in the pores; 2, 2/ - plastic properties with capillary water; 3, 3/ - solid state of the soil with tightly bound water in their pores.

Any particle of clay soil at a given voltage requires a certain amount of water to create its diffuse layer of ions. At humidity less than optimum ($W<W_{opt}$) for full development of a diffuse layer of water it is not enough. The concentration of electrolytes is high. This reduces the repulsive forces between the particles and causes a tendency to flocculation of particles (aggregation in the flake) of the soil (Fig. 2). As the humidity increases to $W_{opt}$ (optimal), the diffuse layer around the particles increases. The concentration of electrolytes decreases. The tendency to flocculation also decreases, but the repulsion between the particles increases, which acts as a lubricant, allowing the particles to slide one by one. When compacted, this leads to a better location of the particles and obtain a parallel orientation.

Therefore, at optimum humidity the maximum density of soil is reached. A further increase in humidity to the values of $W>W_{opt}$ leads to the formation of an even larger diffuse layer around the particles. It also leads to an increase in repulsive forces and to the creation of a dispersion structure with a parallel orientation of the particles. However, the density of the soil, due to the lower concentration of particles per unit volume, will be less. With the transition from low humidity to optimal compaction, the amount of air in the soil will decrease significantly. With the transition from optimal humidity to a higher decrease in soil air content is almost not observed.

During the construction of embankments, the material is compacted. However, the material can be compacted as much as possible only when the optimum humidity of the material is achieved. For this purpose, the laboratory determined the optimal soil moisture using the method of maximum soil compaction using the device MDU-1 (Fig. 3).

A sample of the soil mixture was placed in a thin layer on the bottom of the tank, then moistened evenly with a laboratory burette. With this method of moistening the moisture in the soil was distributed evenly. The soil was thoroughly mixed and poured into a pre-assembled and lubricated with machine oil glass device MDU-1.

The design of the MDU-1 device consists of a basic plate and a reducer, the electric motor, a rack with arms, a core on which weights move. The design of the drive is made in the form of two hinged rods. This design ensures a constant height of the weight of the weight in the process of compaction of the sample. A variable shape is attached to the plate [10]. The mixed and moistened mixture was kept in a desiccator for about 2 hours in order to evenly distribute moisture. The mixture was poured into a beaker from a height of about 10 cm. The height was the same for all samples. Prior to compaction, the sample was compressed for several minutes with a static load weighing 10 kg. This was done to reduce macro pores and air voids. Experiments on the dynamic compaction of the samples were performed when the initial height of the samples is equal. Before compaction, the soil level in the beaker was checked with a depth gauge. After compaction of the soil, the weight of the glass with the soil is determined with the 1 gram accuracy. Then two samples were taken to control humidity. A steel beaker with a prepared soil sample was installed on the base plate of the MSU-1 device (Table 1).

**TABLE 1** Technical characteristics of the device for dynamic sealing

| Equipment Characteristics | The Value of the Characteristics MDU-1 |
|---|---|
| Cargo weight, kg | 5,15 |
| Height of fall, sm | 6,95 |
| The work of one blow, J. | 3,76 |
| Shock impulse, N s | 12,16 |
| Number of beats per minute | 78 |
| The diameter of the glass, sm | 10,0 |
| Height of a glass, sm | 20,5 |
| Accuracy of registration of deformations, mm | 0,1 |
| Motor power, W. | 250 |
| Height of the device, sm | 155 |
| Width of the device, sm | 60 |
| Weight of the device, kg | 65.0 |

Deformations of the soil during the experiment on the device MSU-1 are measured with a depth gauge from the top of the glass after each impact with the number of strokes up to 10. The experiment was stopped if the difference in deformation during the last 10-15 strokes is less than 0.5 mm. With these characteristics, samples of the compacted mixture were made to assess its compressibility in the compression device.

General soil deformation during compaction consists of elastic and residual deformation:

$$S = Sel + Sres. \quad (1)$$

Consequently, the work of external forces will be directed to the elastic and residual deformation of the soil:

$$Aext = Ael + Ares. \quad (2)$$

At the beginning of compaction, the proportion of elastic deformation is small. The bulk of the work of external forces is spent on irreversible deformation of the soil. The work of external forces remains constant during each compaction cycle. In this case, the ratio between the values of the work spent on overcoming the elastic and permanent deformation changes.

Residual deformation dies out with an increase in the number of sealing effects (cycles). With an increase in the number of loading cycles, the increment of residual deformations tends to zero. As a result, all the potential energy of the soil, obtained during the cycle, will be spent on restoring elastic deformations. However, if in the future this soil is subjected to a higher load, then the accumulation of residual deformations will resume and will continue until a new balance is established between the work of external and internal forces.

The method consists in determining the dependence of the density of dry clay soil on its moisture during compaction of samples with a constant cost of work on their compaction (with the same effort for their compaction). The next stage is to determine the maximum value of soil density ρd according to this dependence. The method of dynamic compaction is based on the systematic measurement of deformations of the samples. The samples are compacted in conditions of constant humidity by a continuously increasing number of cargo impacts of constant mass falling from constant heights.

For the experiment loess loam was taken. The soil with the required humidity (from 12% to 20% in increments of 2%) was made and left for even distribution of moisture. The soil was pre-crushed and sieved through a sieve with 1.0 mm holes. 3 kg samples were prepared for further experiments to determine the optimal soil moisture for its maximum compaction [11]. The dimensions of the metal cup are $h$ = 127 mm, $d$ = 100 mm. The weight of an empty metal cup is 4800 gr.

For the experiment, loam loess with natural moisture of soil samples $W$ = 0.16 was used with humidity at the yield strength $W_L$ = 0.28, humidity at the rolling limit $W_p$ = 0.19.

Determination of optimal humidity was performed with drilling mud of the West Kharkiv oil and gas condensate field of well No. 529. It was determined that this drilling mud belongs to the liquid loam. Humidity of drilling mud was 65%. The study was conducted according to standard laboratory methods of soil research according to DSTU B B.2.1-17: 2009 [10].

According to the results of the experiment, it was found that the optimal humidity of the loam is 17.5%. The calculated value of the optimal soil moisture can be taken for preliminary assessment as the moisture on the verge of unrolling. In this case, the discrepancy between these values is 2%. A study was carried out with the addition of drilling mud to the soil in a ratio of 90:10. The optimum humidity of the mixture should be 17.5%, so at a moisture content of drilling mud of 65%, the humidity of the loam should be 13.85%. The loam has a natural moisture slightly higher than the specified value, so the soil was pre-dried and brought to a given humidity in the laboratory.

Next, the procedure of compaction of the mixture of soil and drilling mud was performed using the device MDU-1 (Fig. 3, 4).

As a result of the interaction of the three-phase soil with the external load, the volume of each of the components changes. This leads to a change in the physical and mechanical properties of the entire system of soil mixture and drilling mud as a whole. Solid particles interact with the liquid phase - water. The nearest water molecules are firmly held on the surface of solid particles and form tightly bound water. Subsequent layers of molecules form loosely bound water. Free water and different types of bound water differ in their properties, so the nature of the interaction of the liquid phase with others will be determined not only by the quantitative but also the qualitative content of different forms of water. Compaction of three-phase soil occurs due to compression of the entire system. This phenomenon is accompanied by a restructuring of the three-phase system and a change in the relationship of the components [1]. The external load first compresses the air, which is the most mobile, it is compressed through the pores of the soil mixture. The compressive air resistance is negligible. Therefore, almost immediately after the application of the load, the main part of it is transferred to the soil skeleton. First, there is a convergence of individual units and lumps of soil, then there is a mutual sliding and convergence of the most solid particles in the middle of the units. This changes the orientation of the particles, increases the degree of filling of soil pores with water. Only those particles are moved under load, for the movement of which the magnitude of the applied load is sufficient. Simultaneously with the skeleton, the liquid phase moves to a more stable position.

The air has a noticeable resistance to squeezing only at the last stage of compaction, when it is trapped in the pores of the soil. The three-phase system is approaching two-phase. Complete removal of air from the pores is impossible, some volume of air always remains in the form of soil trapped in the pores, so a clear boundary between two-phase and three-phase soil is difficult to calculate. The volume of compressed air when compacting three-phase soil is approximately equal to the decrease in the total volume of soil. A very small part of the reduction in soil volume can be attributed to the compression of trapped air or its dissolution in water.

**FIGURE 3**. Photo of the MDU-1.

**FIGURE 4**. Glass of the MDU-1.

The experiment determined the increase in the modulus of deformation of the soil mixture with drilling mud at a ratio of soil and drilling mud 90:10 (Table 2). Which makes it possible to dispose of drilling mud by using it in road construction. Drilling mud is a mixture of extracted rock and drilling mud residues. These wastes belong to hazard class IV - this is the lowest hazard class. That is, with the addition of a small amount of drilling mud (about 10%) there will be no significant environmental load. However, before using drilling mud in the construction of foundations, it is necessary to determine its chemical composition and assess the maximum domestic concentrations of substances that are part of it.

**TABLE 2.** Determination of the average modulus of deformation of compacted samples

| Measurement value | Loess loam (compacted) | Loess loam with the addition of 10 wt.% drilling mud |
|---|---|---|
| Average value of the modulus of deformation, MPa | 26.3 | 27.4 |
| Coefficient variations, υ | 0.012 | 0.14 |

# CONCLUSIONS

Based on the results of the analysis, it can be concluded that in the process of compaction of clay soil with the help of dynamic soil compaction in the device MDU-1, the soil forms a structure different from the natural and destroyed components. Therefore, the mixture of clay soil with drilling mud 90:10 at optimum humidity can be characterized by a dispersion structure.

The increase of the average modulus of deformation of the soil-drilling mud mixture at the ratio of soil and drilling mud 90:10 by the value close to 4% is determined. This makes it possible and efficient to use drilling waste in the construction of embankments in railway construction. However, it is necessary to determine the strength properties of the mixture of soil and drilling mud in other ratios.

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