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# Hydromechanical Method of Soil Compaction

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**Abstract.** One of the effective methods for improving the physical and mechanical properties of soils of the foundations of structures is their compaction. The correct implementation of the compaction process significantly increases the bearing capacity of the foundation, evenly distributes the loads from the structures to the foundation, ensuring the stability of the upper and lower prisms of soil dams, reduces water seepage through the body of dams, increases the likelihood of maintaining the structure of compacted soils under the action of dynamic and seismic loads. For soil compaction, static, dynamic, and vibrational methods are used. These methods have a great effect when soil moisture is reached to range within 16 to 18%. Basically, various roller designs are used in soil compaction of earth structures. A review of existing soil compaction machines is given. The disadvantages of the existing soil compaction machines are their massiveness (roller mass up to 40t), the number of passes in one place (three or four), high consumption when watering the soil surface, and waiting for dry-up after watering each soil layer. The article recommends new designs of soil compaction, which eliminates the disadvantages of existing machines, namely: roller is reduced by 50-60%, water consumption is reduced two times, and the number of passes is reduced to one pass.

## 1. Introduction

Soil compaction is the process of its irreversible deformation by external force or due to gravitational forces, which result in a certain decrease of soil volume due to the removal of free water and air from its pores, and the increase of its density. When the soil is loaded, water and air partially come to the surface and partially move in the soil from more stressed to less stressed zones, which result in achieving the required density by repeated loading [1, 2, 3, 4, 5, 6].

The basic earth structures and roads are formed by the compaction of transported soil. Soils are brought mainly by dump trucks and self-propelled scrapers are often used too. Imported soils are leveled in layers and sealed with special soil compacting machines (various design rollers) [7, 8, 9].

Rollers can be trailed, semi-trailed, and self-propelled. Self-propelled rollers are used to compact road surfaces, trailed are used for rolling soil. The working bodies of the rollers are flangs or wheels. Depending on their design, rollers are distinguished as follows: smooth flang rollers, cam rollers, trellised rollers, segmented and pneumatic wheel rollers. Rollers with smooth flangs and on pneumatic tyres are suitable for compaction of both incoherent and cohesive soils. Cam and segmented rollers can only compact cohesive soils [10, 11, 12, 13, 14, 15, 16, 17].

Rollers can be light, weighing 3 ... 5 tons with a contact load of 20 ... 40 kN / m; medium, weighing 6 ... 10 tons with a contact load of 40 ... 60 kN / m; heavy, weighing 10 ... 15 t with a contact load of 60...80 kN / m and super heavy, weighing 17 ... 25 t with a contact load of 80 ... 120 kN / m.

The parameters of the cam rollers (Fig. 1) should be selected by taking into account the properties of soils. The mass of the cam rollers should be such that during the first pass the cams (Figure 1) are

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immersed to their full length (cam length 25 ... 30 cm, 20 ... 25 cam pieces are installed for every 1 m2 of the area), and drum 5 only touches the layer to be compacted. In this case, the gravity of the roller will be transmitted to the soil through the cams. With excessive mass, the roller acts on the soil with a drum, not with cams. In this case, the sealing effect may decrease, since the cams will be unloaded. With an insufficient mass of the roller, the effect of the impact will also decrease, since its cams at the initial stage of compaction will not completely immerse in the soil, which will lead to a decrease in the compaction depth. To increase the mass of the roller, the drum is replenished with metal balls or lump stones through the roof 6.

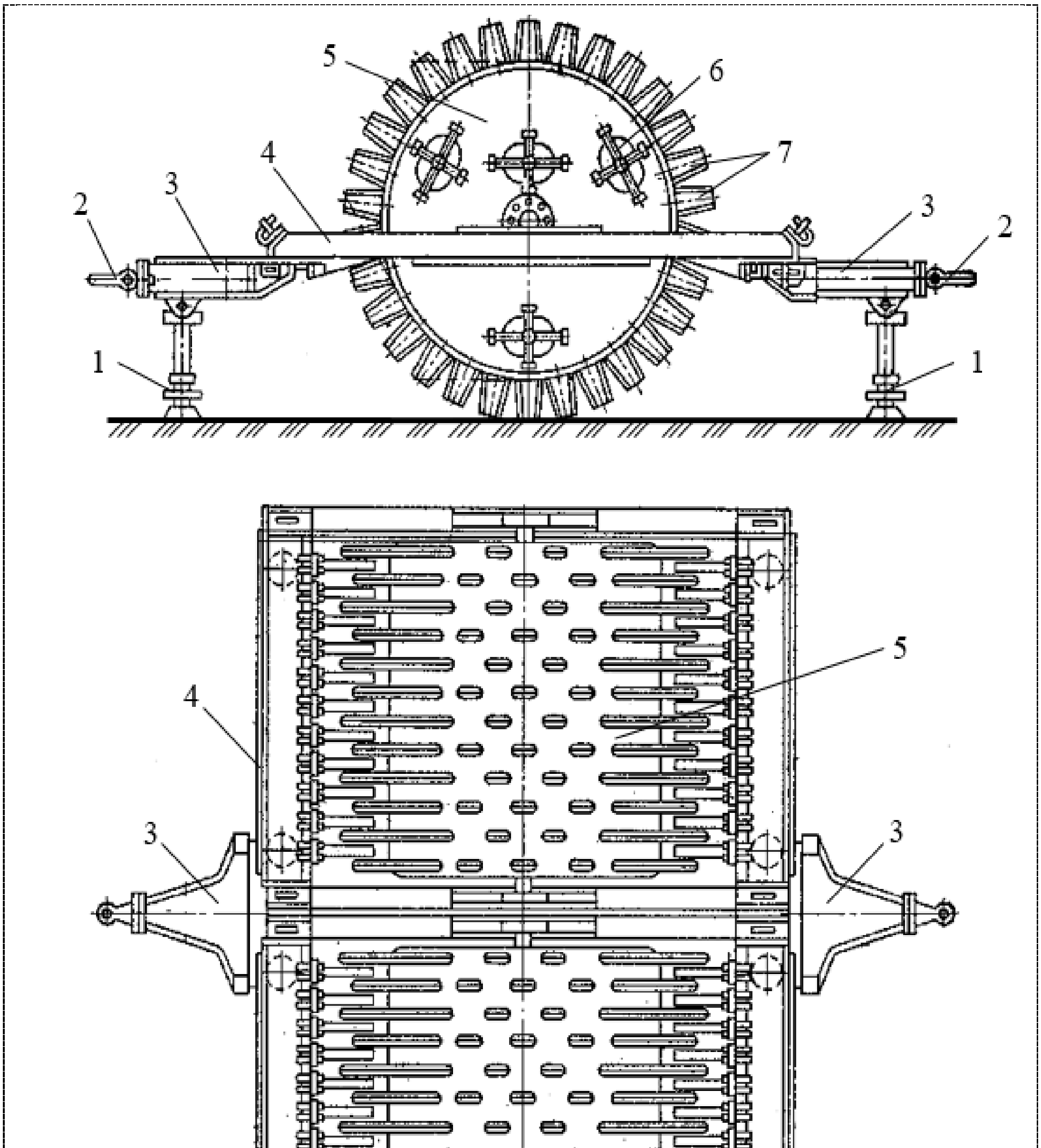

**Figure 1.** Cam roller design: 1 is pillar; 2 is hook; 3 is traction frame; 4 is roller frame; 5 is roller; 6 is roof; 7 is cams.

Rollers on pneumatic tires, provided that their parameters are correctly selected, are suitable for compaction of both cohesive and non-cohesive soils. To bring the soil to the same density, a pneumatic roller requires fewer passes, which increases the productivity of the process.

Compaction of the soil with pneumatic rollers (Figure 2) is carried out by tire (tires are installed in 4 or 6 rows), which is deformed and has a larger contact area with the soil than with a smooth flang. At the initial passes of the pneumatic wheels, when the soil is in a loose state, the deformation of the tire compared with the deformation of the soil is small, which is why the operation of the pneumatic tire is similar to the work of hard flangs. As the soil is compacted, the relative value of the tire deformation keeps increasing, and with dense soil surfaces, the tire is deformed. To entrain the mass of the roller, a hopper is installed on each tire, which is loaded with special reinforced concrete slabs.

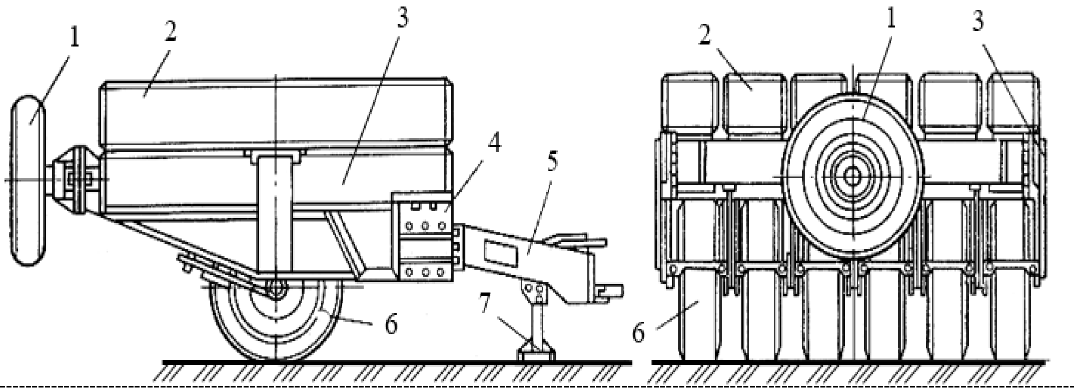


**Figure 2.** Pneumo roller Designs: 1-spare tire; 2 reinforced concrete slab; 3-hopper; 4-roller frame; 5-traction frame; 6-bus; 7-pillar

Soil compaction by static methods is effective at an optimum moisture content of 17-18%. If soil is compacted and has a low moisture content (10 ... 16%), then it should be increased by adding additional water. The supply water for soil moistening is done by water trucks. Water truck waters the surface of the compacted soil layer. After drying, the surface of the soil (it takes 1 to 3 days depending on temperature), compacting machines are launched onto the surface of the soil.

The main disadvantages of cam and pneumatic rollers are:

- metal-intensive;
- multiple passages in one place;
- lower compaction coefficient at low soil moisture.

Ramming machines compact the soil to greater depths (up to 2 m). These machines are less sensitive to soil moisture and can be used to compact various types of soil - from sandy to heavy clay.

The most widespread among these machines is ramming cargo based on a single-bucket excavator, which is one of the types of interchangeable working equipment (Figure 3). Compaction is carried out by the impact of a free-falling load with a mass of 1 to 4 tons. The load falls from a height of 2 to 3 m, and upon impact, it creates 15 to 50 kJ of energy. Cargo material is cast iron or reinforced concrete. The lifting of the cargo is carried out by a lifting rope of an excavator winch [6].

Ramming machines are especially suitable for compacting soils in tight spaces.

The disadvantages include relatively low productivity, design complexity and high cost of work.

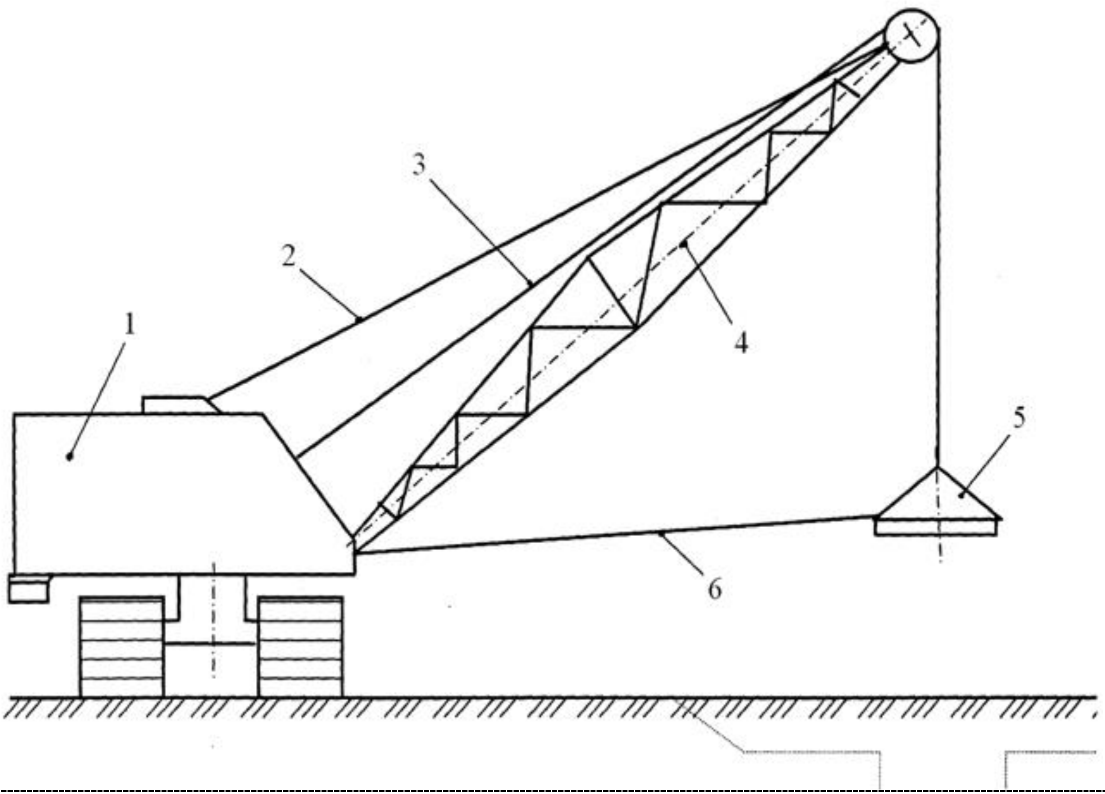


**Figure 3.** Tamping machine design: 1 is excavator; 2 is boom hoisting rope; 3 is cargo hoisting rope; 4 is arrow; 5 is cargo; 6 is traction rope

## 2. Methods

Our preliminary studies have shown that the most acceptable method for soil compaction is the theory of soil compaction of the basis of hydraulics and a comparison of the existing and recommended method of soil compaction [18, 19, 20]

The results of the soil compaction research revealed the following major disadvantages of existing techniques and technologies:

- reduce the mass of the compacting machine by two or three times;
- reducing the amount of water required for soil moistening by 1.5 times;
- reduce the number of transitions machines in the soil;

this requires the production of new equipment and technology.

These deficiencies of hydro-mechanical compacting techniques and technology of the soils are addressed in the article.

It is known that it is one of the constituents of soil. By introducing water into the soil, air pores can be extracted, and also water lubricates the grain edges of the soil, thereby the soil grain is conveniently stacked, therefore the volume of soil is reduced to 20%. This shows that the soil can be compacted by water and external pressure, which is called the hydro-mechanical method.

Figure 4 shows a general view of hydro-mechanical compacting equipment in laboratory conditions. The equipment consists of the following main components: mass roller 60 kg ( 60 cm wide and 60 cm in diameter); roller pull frame; 60-liter water tank; soil knife blade; water sprayer.

Soil humidifier is mounted on the front of the installed rod with basic and special frames. It has several soil-cutting knives and water sprayers 30 cm in length and 20 cm in the perpendicular frame, which is lifted and lowered using a hydro cylinder.

The sprayer is made of metal pipes with a diameter of 20 mm, the length is 25 cm, in the front of the sprayer the roller has several 2 to 3 mm holes staggered on its side (10 ... 12 pieces). The water tank is connected to the metal main pipes by bending a rubber hose and a screw is installed between the tank and the hose for opening and shutting the water supply. Sprayer receives water from the main tank via metal pipes. The water is then fed to the sprayer by the pressure created from the flow of the water column in the tank. Water can also be obtained from a water truck. The moisturizing device, with the help of the hydraulic cylinder, is lowered and introduced into the soil when the roller frame is moved, the wedge-shaped knife cuts the soil, creating a gap, the sprayer is installed on the back of the knife, with several holes through which water is sprayed into the soil. As a result, the soil is moistened, and, at the same time, the gravity of the roller compacts the soil. When the soil is wet, the space (air) between the particles is filled with water, which reduces friction between the particles. In this case, simultaneously, the pressure applied on the floor of the coil causes high-quality compression.

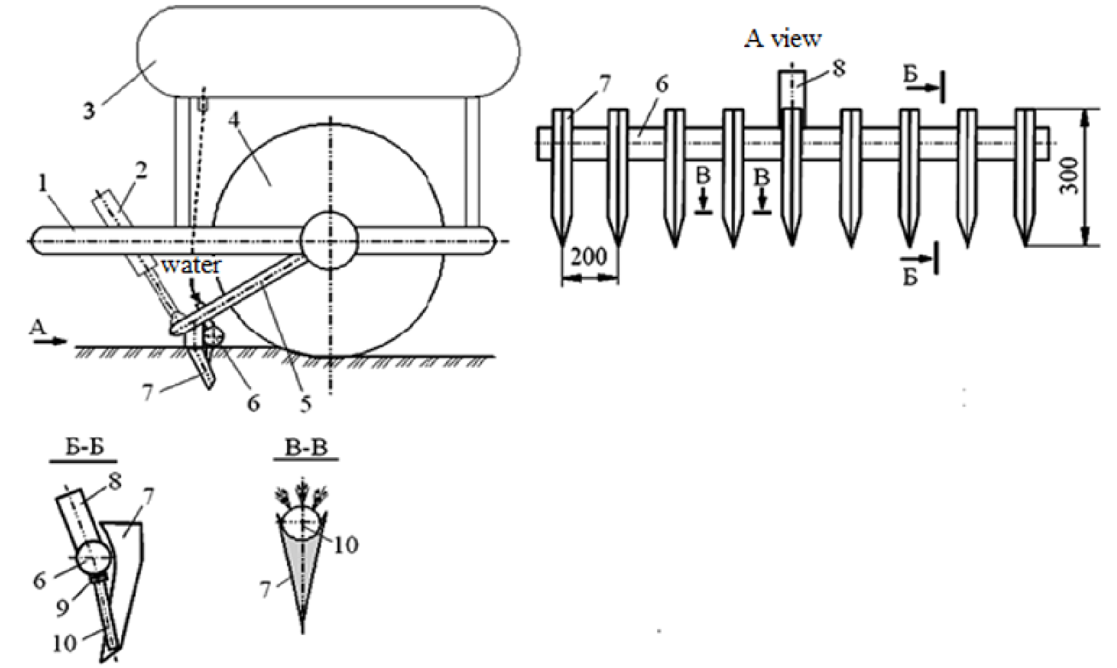


**Figure 4.** Hydromechanical soil compaction method: 1 is main frame; 2 is hydrocylinder; 3 is water tank; 4 is roller; 5 is framework for work; 6 is main water pipe; 7 is soil cutting knife; 8 is a tube; 9 is counter nut; 10 is water sprayer.

Laboratory studies have shown that the simultaneous soaking of the soil can reduce the weight of the currently used rollers by as much as 30 to 40%.

The amount of water available for soil moistening must meet the following conditions:

$$Q_g \leq Q_w \quad (1)$$

where: $Q_g$ is the amount of water required to be soaked, m$^3$/hour; $Q_w$ winter is the amount of water supplied by the water supply unit, m$^3$/hour.

The amount of soil to be soaked is determined by the following formula:

$$Q_g = B \cdot h_m \cdot \frac{W_o - W_n}{100} \cdot \vartheta_w , \qquad m^3/h \quad (2)$$

where: $B$ is the width of the roller, m; $h_m$ is the soil layer to be specified moisture, m; $W_o$ is water moisture content, %; $W_n$ is natural soil moisture, %; $\vartheta_w$ is the walking speed of the machine, m/h.

The amount of water required by the equipment is as follows:

$$Q_w = 3600 \cdot \mu \cdot \frac{\pi \cdot d^2}{4} \cdot n \cdot \sqrt{2gh} \quad \text{m}^3/\text{h} \tag{3}$$

where: $\mu$ is the hydraulic coefficient considering the amount of water in the pipes and holes; $d$ is the diameter of the water outlet openings when the soil is wet, m; $h$ is the height of water column in the system, m.m.c; $n$ is the number of holes in the system.

Using the formulas (3) and (4), the number of holes can be determined as follows:

$$n = \frac{B \cdot h_m (W_o - W_n) \cdot \vartheta_w}{25 \cdot \mu \cdot \pi \cdot d^2 \cdot \sqrt{2gh}} \tag{4}$$

The research was carried out in laboratory conditions, using specially made smooth rollers, with traditional and proposed methods.

The research results from the proposed method were compared with ones with traditional methods.

## 3. Results and discussion

Soil compaction with the help of a roller was carried out without a lock and with a lock by rolling it on the soil surface. Soil moisture was determined before and after the lock, as well as the density of compacted soil with and without the lock. Wherein, in a checkerboard pattern, a compacted soil layer was obtained at various points to determine its density.

The results of the study are shown in the table.

**Table 1.** Density of compacted soil with and without lock.

| Natural moisture of the compacted soil layer,% | Moisture of the soaked soil layer,% | Roller mass, kg | Roller Width, m | The average density of the compacted soil without locks, g/sm$^3$ | The average density of the compacted soil with a lock, g/sm$^3$ |
|---|---|---|---|---|---|
| 16 | 22 | 60 | 0.6 | 1.44 | 1.73 |

## 4. Conclusion

The following conclusions can be drawn from the results of research work on static compaction of soil:

- the mass of the static compression roller is reduced by 50-60%;
- when the compacting soil is hydrodynamically recommended, it is possible to achieve the required soil density, as well as with single rotation of roller;
- the amount of water used for soil moistening is reduced by two times;
- the pressure on the soil will increase due to the weight of the water tank and the load on the top of the roller help to achieve the required soil density.

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