Recent Development of Dynamic Consolidation Method

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Abstract. With the rapid development of expressway construction in China, the quality of expressway engineering has been paid more and more attention. Because the highway foundation filling is generally high, the foundation must bear the dual pressure of vehicle load and much larger than the filling load, so the strength and stability of the highway foundation cannot be ignored by highway technicians. The dynamic consolidation method has been proved to be a good and effective foundation treatment method by practice, so it has been widely used in the reinforcement of soft foundation of expressway, and it is a kind of soft foundation reinforcement method worthy of popularization and application, but there are still many theoretical problems to be solved, and the design and calculation methods need to be improved.

1. Introduction

Dynamic consolidation method is also called dynamic consolidation method or dynamic compaction method. This method is a method of repeatedly tamping the foundation with heavy hammer, which is generally referred to the height to make it fall freely, so as to improve the strength and reduce the compressibility of the foundation. Because the dynamic compaction method is economical, feasible, effective, simple in equipment and convenient in construction. Easy quality control, wide range of application, material saving, short construction period, has been rapidly promoted for the country. Economic construction has played an important role.

| Soil Category         | Soil properties | Suitable or not                  |
|-----------------------|-----------------|----------------------------------|
| impermeable soils     | $k > 10^{-8} \text{m/sec}$, $PI > 0$ | not recommended                  |
| permeable soils       | $k > 10^{-5} \text{m/sec}$, $PI = 0$ | improvement is achievable        |
| intermediate permeable| $10^{-8} > k > 10^{-5} \text{m/sec}$, | dissipation of pore              |

* $k$ is permeability coefficient. $PI$ is plastic index;

The dynamic compaction method has been popularized very quickly, because it is a reinforcement method mainly to give full play to the potential of the soil layer itself. The basic point is to drop the...
heavy hammer from a high place, which can obtain a larger load than the static load of the weight of the hammer. On the basis of compacted soil layer under impact load, the bearing capacity is obviously improved, and other mechanical properties are also discussed. It has also been improved. This is an active reinforcement method, making full use of and exerting the role of the soil layer itself, which is in line with the requirements. The general principle of making full use of the function of rock and soil mass itself.

2. Consolidation mechanism
The dynamic consolidation of porous, coarse and unsaturated soils is based on the dynamic compaction mechanism, i.e. impact type. Dynamic load decreases the pore volume and makes the soil compact, thus improving the strength of foundation soil. The process of compaction with soil is the process of extrusion of vapor phase air in soil. The compaction deformation is mainly caused by the process of extrusion of vapor phase air in soil. It is caused by the relative displacement of soil particles.

From the point of view of ramming energy transmission, ramming hammer falls from a high place, and ramming energy can propagate through different paths in the soil layer. One is that ramming can propagate radiation from the bottom of the ramming pit to the surrounding area parallel to the ground. Its propagation front is cylindrical, i.e. cylindrical radiation propagation; the other is ramming can radiate to the deep, and its wave front is hemispherical, i.e. spherical surface. Radiation 3 is a one-dimensional propagation mode, i.e. plane emission mode of non-radiation propagation, because the direction of the rammer's force on the ground is vertical downward, and the rammer's vertical downward propagation is obvious. In the process of soil compaction, there are still different opinions on which kind of compaction can play the main role. It is generally believed that the one-dimensional wave and spherical wave propagating in the soil layer play a major role. It is also believed that the tamping effect is mainly one-dimensional wave, supplemented by other. Because the surface wave in dynamic compaction is confined to a certain depth of the ground, it radiates along the ground with the compaction point as the centre, which is a kind of cylindrical radiation. If the compacted energy of the soil layer is mainly transmitted in this way, there will be some corresponding deformation marks on the ground, or the size of the compacted pit ground is larger than the size of the bottom of the rammer, or the compacted point ground is in the shape of the bottom of the pot which is gradually decreasing from the middle to the surrounding. If the tamping is dominated by spherical radiation propagation, the ground may also be the bottom shape of the pot with the tamping point as the centre. The above ground traces and phenomena are rarely seen during dynamic compaction. The size of the bottom of the compaction pit is exactly the same as that of the hammer. The depth of the ramming pit is often tens or even nearly 100 centimetres, reflecting the characteristics of the vertical displacement of the soil particles at the bottom of the hammer, and the lateral extrusion effect is relatively small.

For saturated soils, besides pore water, there are organic matter decomposition in the soil. There are always some tiny bubbles in the soil, whose volume accounts for one of the whole volumes. When dynamic compaction is carried out, gas volume is compressed, pore water pressure increases, then gas expands, pore water is discharged, pore water pressure decreases, and solid volume remains unchanged. Thus, liquid volume and vapor phase volume are constant every time of ramming. It reduces to a certain extent, causing the saturated soil to produce compression and settlement at the moment of dynamic compaction.

When the tamping energy increases to the saturation energy, the pore water pressure rises to equal the overburden pressure of the upper soil layer. The pore water pressure dissipates rapidly after tamping stops. Under the action of large tamping energy, great stress and shock waves appear in the soil, resulting in cracks in the foundation, forming a dendritic drainage network, and pore water can be discharged smoothly. Vertical fissures on the surface are distributed around the tamping point. During dynamic compaction, the local liquefaction of soil results in excess pore water pressure greater than the transverse pressure between particles, resulting in cracks between particles, forming drainage channels, and the permeability coefficient of soil increases sharply. When the pore water pressure...
dissipates and reaches the transverse pressure less than that between soil particles, the cracks close, the soil particles contact each other more closely, and the strength of the soil increases.

3. Effective depth of reinforcement

The influence depth of soil reinforcement is one of the key considerations of any foundation treatment method. In dynamic compaction method, the reinforcement or influence depth is not only the main basis for the design of superstructure foundation, but also plays a direct role in determining the energy of dynamic compaction, the arrangement of compaction points and the uniformity of reinforcement. Effective reinforcement depth of dynamic compaction is a complex problem, which has many influencing factors. For example, the size of ramming energy, the types and properties of soil, the thickness and burial order of different soil layers, groundwater level, other design parameters of dynamic compaction and ramming technology will all affect the effective reinforcement depth, which is mainly determined by the single-hit ramming potential energy, especially the single-hit ramming potential energy on the bottom area of the unit rammer. At present, most of the calculation methods of effective reinforcement depth are still based on the modification of Maynard’s empirical formula combined with the local actual situation. In the absence of data, the consolidation depth can be estimated approximately by the arithmetic square root value of the single-tap ramming energy per unit area of the bottom of the rammer, or the single-tap ramming energy used can be determined preliminarily according to the required depth of consolidation and the existing rammer. Therefore, since Mena dynamic consolidation depth formula came out, the research on this aspect has been uninterrupted, and some achievements have been made. Generally speaking, there are three aspects. Menard et al. proposed the following equation to estimate the reinforcement depth $H$:

$$H = \sqrt{Mh}$$  \hspace{1cm} (1)

where $M$ and $h$ are the weight of hammer and height of falling respectively. There is no strict definition of the influence depth of reinforcement. Reinforcement should be a certain depth below the surface. After dynamic consolidation, all kinds of strength indicators of soil are improved in the original foundation. For engineering, it must meet the strength indicators of the design requirements, otherwise it cannot be said of reinforcement. Only the depth of reinforced soil can be understood as the depth of reinforcement, and the influence depth is more extensive. The strength index of soil can also be improved or reduced. As long as the characteristics of upper rest change, it can be understood as affected by it.

Based on a large number of Engineering practices, the existing literature considers that the size of the bottom area of dynamic compaction hammer is related to the capacity of crane itself, and the bottom area is too large, which is limited by the lifting angle of the equipment pole. Second, it is related to the type of foundation soil to be strengthened. Generally speaking, for coarse grains such as sandy soil and gravel fill, one rammer with small bottom area is used, for cohesive soil, and for silt soil, one rammer with large bottom area is used. The reason is that for silt soil, if a small area rammer is used, it will penetrate too deep into the soil and suck the hammer, which makes it difficult to start the hammer, but it has little effect in coarse-grained soil.

4. Parameter analysis

The reinforcement range of dynamic compaction is studied from the angle of momentum theorem or energy conservation principle. The area of hammer bottom directly determines the impact pressure when hammer strikes the ground, and then affects the effective reinforcement depth of dynamic compaction. If the hammer bottom area is too large, the impact stress per unit area will be small, which is not enough to destroy the soil structure, and the penetration degree will be small. The more tamping times are needed to achieve the same reinforcement effect. The reinforcement effect is not significant. If the hammer bottom area is too small, although the impact stress per unit area increases, the soil structure will be easily destroyed, the penetration degree will be large, and the tamping times required will be less. Good reinforcement effect can be achieved, but the plastic state of the soil is easy to extrude to the side, while the hammer bottom area is too small, the tamping points needed for
tamping must be increased accordingly, thus increasing the amount of work. Therefore, only by choosing the appropriate hammer bottom area, can the relatively satisfactory reinforcement effect be obtained.

The number of times of tamping and the number of tamping per tamping point are two related parameters. When the total number of tamping strikes at each strike point is determined, different times of tamping are adopted according to soil conditions. For soils with fine grains, weak permeability and high-water content, it is advisable to reduce the number of tamping times per time and increase the number of tamping times. For soils with coarse grains, strong permeability and low water content, it is advisable to increase the number of tamping times per time and increase the number of tamping times. For the soil with coarse grain, strong permeability and high-water content, it is better to increase the number of tamping times per time to reduce the number of tamping times. For the soil with coarse grain, weak permeability and high-water content, it is better to reduce the number of tamping times per time and increase the number of tamping times. For the soil with coarse grain, strong permeability and low water content, it is better to increase the number of tamping times per time to reduce the number of tamping times.

5. Conclusions
In this paper, the mechanism of dynamic consolidation is studied, and then the factors influencing the effect of dynamic consolidation are discussed. The research shows that dynamic compaction is a kind of reinforcement mechanism to give full play to the impact load. Firstly, the strong impact force acts on the soil instantaneously and produces shock wave in the soil. Under the impact wave, the soil under the rammer is compacted rapidly, so that the soil can be reinforced. At the same time, the shock wave produces vibration in the soil and reinforces the surrounding soil.

Geotechnical engineering is a subject with strong practicality, and the development of its theory can not be separated from engineering practice. Simplified theoretical analysis and numerical analysis methods also need some empirical data to support, in order to obtain more accurate results. Therefore, the development of dynamic compaction theory can only be promoted by the integration of various methods. Although the dynamic compaction method has been successfully applied to the treatment of poor foundation, its theoretical research needs to be further deepened. Only the combination of theory and practice can promote the development of dynamic compaction theory and make the construction proceed under the correct theoretical guidance.

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