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Study on the Effect of Steel Wheel and Ground on Single Steel Vibratory Roller

Jiabo Li[1,*], Guanghui You[1], Jiabin Qiao[1], Min Ye[1], Jin Guo[1], Hongyang Zhang[2]

[1]State Key Laboratory of Engineering Machinery, Chang'an University, China
[2]Zhejiang Ocean University, Zhejiang, China

*Corresponding author e-mail: 562570245@qq.com

Abstract: In the compacting operation of single drum vibratory roller, the forces acting on the foundation of drum include the weight of the drum, the weight of the frame, the exciting force and so on. Based on the theoretical study of ground mechanics, this paper analyzes and calculates the forces acting on the steel wheel and the ground, and obtains the distribution of the laminar stress in the ground when the working plane vibrates. Derive the formula of dynamic compressive stress and static compressive stress in the foundation during vibration compaction. Through the compaction test of the soil trough of 20T single drum roller, the compressive stress data of the soil hydraulic field are obtained. The data of the dynamic compressive stress and the static compressive stress of each layer during the third compaction are obtained, and the theoretical research is verified.

1. Introduction

As the main equipment for compacting soil, the single-drum vibratory roller is mainly used for compaction of the base and grass-roots. It is the main equipment for compaction. Due to the random nature of the soil physical properties, the effective force of the vibrating wheel on the foundation cannot be directly measured by the existing equipment, but the compaction of the steel wheel is of great significance. By analyzing the effective acting force of the vibrating wheel on the foundation, The transmission system, the vibration system, and the design of the steel wheel parameters provide an important basis[1]. Through the combination of theoretical research and experiments, this paper analyzes the composition of the effective force of the vibration wheel on the soil, and compares the changes of the vibration acceleration The composition of vertical stress in soil under the action of vibrating wheel is analyzed.

2. Steel Wheel and Foundation Effect Model

The force F_2 between the steel wheel and the ground is the vector sum of the soil elastic force $K_S Z$

and the earth's damping force C_2Z (Z is the steel wheel's settlement). The K_SZ is related to the instantaneous amplitude of the road roller. C_2Z is related to the vibration and vibration velocity and soil damping. Therefore, F_2 is closely related to the physical properties of soil[2]. Since the physical properties of soil are random, F_2 also has the same randomness. However, with the same soil compaction, F_2 with a variety of factors less affected. The study of the change of F_2 can be obtained by analyzing the compressive stress of the foundation layers. The mechanical properties of the soil in the foundation determine the stress distribution in the soil under the action of the steel drum. The most basic mechanical properties include elastic modulus E, Poisson's ratio μ, cohesion C and internal friction angle

φ. These parameters determine the size of soil shear strength τ_f, thus affecting the soil compaction[3] .

$$\tau_f = C + \sigma\tan\varphi \quad (1)$$

τ_f - shear strength of soil / KPa; σ - normal stress acting on the shear plane / KPa; φ - internal friction angle / °; C - cohesion within the soil / KPa. In formula (1), it can be seen that the shear strength of soil is related to its normal stress as well as its own mechanical properties.

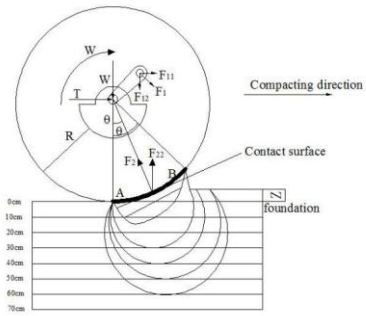

Figure 1: A plot of the distribution of compressive stresses across the foundation of a vibrating wheel at one point

F_1 is the exciting force, F_{11} and F_{12} are the horizontal and vertical components of the exciting force, R is the radius of the steel drum, Z is the settlement, θ is the arc angle between the steel wheel and the foundation, T is the driving force of the rear frame, Pm is Maximum compressive stress. Figure 1 is a 20T single-drum roller theoretical calculation of the steel wheel in the vibration compaction, the foundation of the laminated stress distribution diagram, and the steel subjected to force analysis. Vibration wheel vibration compaction, the reaction force F_2 is passed to the soil, including the allocation of gravity on the vibration wheel, the vertical component of the exciting force F_{22}, vibration wheel (including the internal parts) and inertial force of the front frame[4].

$$F_1\sin\theta + W_g - \frac{W_g}{g}\ddot{x}_g - m_f\ddot{x}_f - F_2\cos\alpha = 0 \quad (2)$$

$$F_1 = mr\omega^2$$

$$F_1\cos\theta + T = F_2\sin\alpha$$

In equation (2), W_g is the weight of the steel drum, F_1 is the exciting force, m is the eccentric block mass, r is the eccentric block eccentricity, ω is the excitation frequency, m_f is the mass of the front frame, g is the acceleration of gravity, $\ddot{x}_g$, $\ddot{x}_f$ is the vertical vibration acceleration of the steel drum and the front frame, AB arc is the contact surface between the steel drum and the foundation, and the resistance of the foundation F_2 to the steel drum is equal to Z and X_d.

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According to the theory of roller vibration, the inertial force and excitation force of the vibration wheel and the front frame are the same, so $F_1\sin(\omega t)$, $\frac{W_g}{g}\ddot{x_d}$,$m_f\ddot{x_f}$ all have the same frequency , It can be synthesized with the same frequency of equivalent force, known as the equivalent dynamic force, while the weight of the vibration wheel $W_g$for a static force. Therefore, the effective force transmitted to the soil by the vibrating wheel should include static force and dynamic force, the static force is the distributed gravity of the vibration wheel, the dynamic force is the exciting force, and the inertial force of the vibration wheel and the front frame is vertical The combination of direction.

3. The effective force transmitted by the vibrating wheel to the soil

Vibratory wheel really for compaction force is not its excitation force, but the vibration wheel and the soil between the force, but also become the vibration wheel to the effective force transmitted to the soil.

$$F = F_e\sin(\omega t) + m_2 g - \left(\frac{W_g}{g}a_d - m_f a_f\right)\sin(\omega t - \varphi_d) \quad (3)$$

In formula (3), F is the effective force transmitted to the soil by the vibration wheel , a_d is the vertical acceleration of the steel wheel, a_f is the vertical vibration acceleration peak of the front frame,φ_d is the phase angle between the vibration acceleration of the vibrating wheel and the exciting force. It can be seen that when $F > F_{22}$, the force exerted by the vibrating wheel on the soil is downward and no separation from the soil occurs. When $F = F_{22}$, the vibrating wheel will jump off the soil and the phenomenon of jump vibration occurs. The proportion of the static forces in the foundations is larger than that of the dynamic ones, and the proportion of dynamic forces increases with the increase of amplitude and compaction times. The vibration acceleration of the vibration wheel when the foundation vibrates shows a certain nonlinearity, that is, the upward vibration acceleration peak value is greater than the downward vibration acceleration peak value[5].

The role of the roller and the ground roller load is equivalent to the line load, set the steel compaction direction is the x-axis positive direction, along the drum width direction for the y-axis direction, the depth of each layer compaction z-axis direction. According to the theory of elastic theory, the formula of the maximum vertical compressive stress in various soil layers can be deduced.

$$\sigma_z = \int_{\frac{-b}{2}}^{\frac{b}{2}} \frac{3\frac{F}{b}z^3 dy}{2\pi(x^2+y^2+z^2)^{\frac{5}{2}}} = \frac{2z^3 F/b}{\pi(x^2+z^2)^2} \quad (4)$$

By calculating equation (4), we can get the maximum stress distribution of each layer in Fig. 1.

4. Experimental analysis

4.1. Changes in the stress and acceleration of the foundation layers

Quality	Static load	Amplitude	Vibration frequency	Exciting force	Wheel width	Drum diameter
t	KN	mm	HZ	N	mm	mm
20	480	2/1	28/35	360/280	2100	1500

Table 1: basic parameters of the prototype

Before the start of the experiment, acceleration measurements were made on the measuring points under the conditions of dangling vibration and low frequency and high amplitude, respectively, and

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compared. Measuring point layout shown in Figure 2. It is found that the amplitude of the acceleration of the vibration wheel upwards is greater than the acceleration of the downward acceleration in low frequency and high amplitude. As some of the soil vibrates along with the vibration wheel, the vibration quality of the vibration wheel increases, so the vibration acceleration amplitude of the vibration wheel in the soil is smaller than the acceleration amplitude of the vibration wheel. Table 2 shows the values of suspended vibration and high amplitude compaction vibration acceleration.

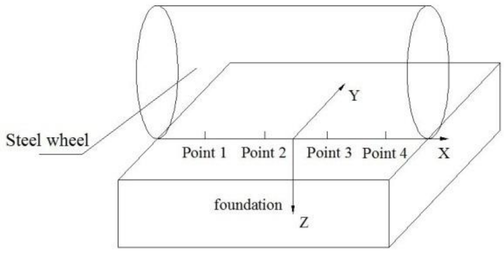
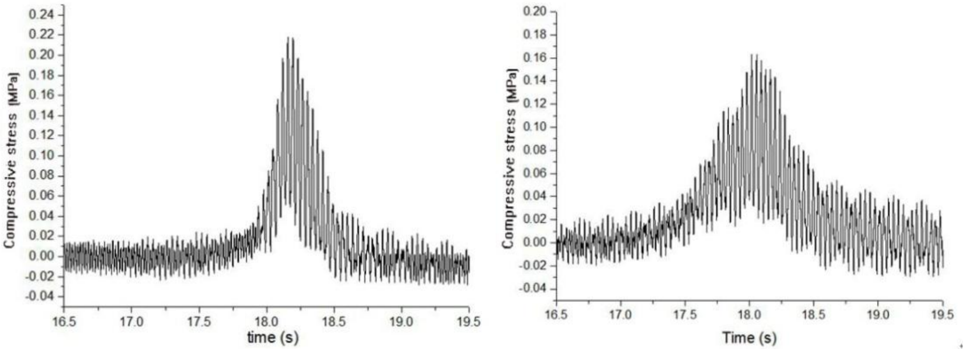


Figure 2: Location map

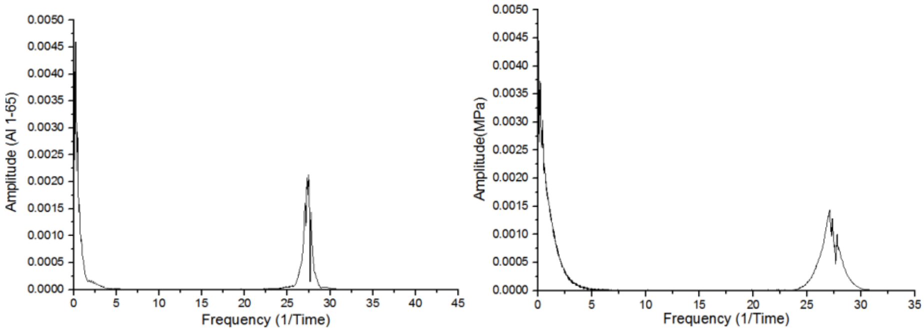
Condition	Measuring point location	Vibration frequency / Hz	Maximum acceleration/m /s^2	Minimum acceleration / m / s^2
Dangling vibration	Measuring point 1	29.3	70.95	-71
	Measuring point 2	29.3	70.3	-70.58
	Measuring point 3	29.3	60.35	-60.23
	Measuring point 4	29.3	69.3	-64.7
Low frequency high amplitude	Measuring point 1	29.3	41.8	-44.93
	Measuring point 2	29.3	36.13	-39.33
	Measuring point 3	29.3	39.62	-41.99
	Measuring point 4	29.3	38.86	-40.04

Table 2: Vibration and high-amplitude compaction vibration acceleration value

At the beginning of the experiment, first of all, the soil was subjected to static pressure twice, and then the pressure sensor was buried at a depth of 0 cm, 10 cm, 20 cm, 30 cm, 40 cm, 50 cm and 60 cm from the soil surface, used to collect the vibratory roller in the low-frequency high-amplitude conditions of soil compaction process stress. The compaction is carried out 3 times with the high profile of roller, and the shape of soil stress at each depth position is basically the same during each compaction. Experiments measured the prototype in the high amplitude file compaction third 30cm layer, 60cm laminated stress curve and dynamic and static force of each layer of the FFT distribution of the law shown in Figure 3.



(a) 30cm layer and 60cm soil stress curve



(b) 30cm and 60cm FFT curves

Figure 3 : Distribution of soil stress in different layers under low frequency and high amplitude

As can be seen from Figure 3, the vertical stress of the soil is in a state of "vibration" during the process of vibrating the soil by vibrating the wheel to vibrate the soil, showing an overall trend of first increasing and then decreasing [2]. The soil vertical stress FFT curve shows that the vertical soil stress consists of two parts during the process of vibrating and vibrating the soil; static stress (0.23HZ) and dynamic stress (27.9HZ), and the static stress value Much greater than the dynamic stress value.

4.2. Effective force

The effective force F transmitted to the soil by vibrating steel wheels includes static forces and dynamic forces. The corresponding compacted ground also contains static compressive stress and dynamic compressive stress [2]. Therefore, we tested the stress composition of soil under the action of vibration wheel through experiments. The maximum value of soil stress in Fig. 2 is the highest point of the curve. At this moment, the vibration wheel is located just above the sensor. Combined with the FFT diagram can be seen that the soil stress P by the static stress $P_j$and dynamic stress $P_d$composition. The maximum stress and the minimum stress are:

$$P_{max} = P_j + |P_{dmax}| \qquad (5)$$
$$P_{min} = P_j - |P_{dmax}|$$

According to the above equation, the soil stress measured in the experiment is calculated and analyzed, and the static stress and dynamic stress at different depths at the third compaction can be calculated. The depth stress values are shown in Table 3.

depth / pressure	10cm	20cm	30cm	40cm	50cm	60cm
Dynamic stress /KPa	176.58	183.24	142.26	120.32	110.86	96.75
Static stress /KPa	253.42	259.56	189.84	157.89	142.44	122.91
Dynamic stress and static stress ratio	0.697	0.706	0.749	0.762	0.778	0.787

Table 3: Different Depths of Stress Values

From the table we can draw:

(1) At low frequency and high amplitude, the dynamic stress in foundation soil is smaller than static stress, that is, the phase angle φ_(d) between vibration acceleration and excitation force is less than 90 °. As a result, the exciting force and the inertial force of the vibrating wheel are partly canceled, so that the dynamic force is smaller than the static force.

(2) With the increase of amplitude, the ratio of dynamic force to static force increases in all depths of the foundation, that is, the effect of dynamic force on soil compaction will be more obvious.

(3) Calculating the dynamic and static stresses of each compaction pass It is not hard to figure out that at the depths of all layers, with the increase of compaction pass numbers, the soil compaction and stiffness will also increase, the ratio of dynamic force and static force is also gradually increased.

Comparing the theoretical compressive stress value with the actual measured compressive stress value under the same working condition, the theoretical compressive stress value is calculated by the formula 1, and the error is less than 0.3% and the data error is small, which proves that the established model (1) meets the actual requirements. Therefore, when the soil conditions are consistent, the change of the compressive stress of the foundation mainly depends on various parameters of the steel drum. The actual compressive stress and theoretical compressive stress data are shown in Table 4:

The actual value of compressive stress/KPa	429.5	442.79	332.12	276.31	255.29	219.66
Theoretical stress value/Kpa	430.9	442.8	302.1	278.2	253.3	223.6

Table 4: Comparison of theoretical compressive stress with actual compressive stress

Therefore, the effective compaction force of vibrating wheel on the ground, the proportion of static force to be much larger than the dynamic force, the dynamic force has a significant effect on the improvement of compaction degree, which increases with the increase of amplitude and compaction number.

5. Conclusion

The forces acting on the foundation of the steel drum include dynamic forces and static forces. When the static forces are 0 ° and 90 °, the maximum and minimum compressive stresses on the foundation can be obtained. In contrast, the values of dynamic and static forces can be derived from the maximum compressive stress and the minimum compressive stress. During the third vibration compaction, the theoretical analysis and experimental research on the bearing capacity of foundation are carried out. It is concluded that the ratio of dynamic force to static force will also increase with the

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increase of depth in all depths of foundation, that is, the effect of dynamic force on soil compaction will be more obvious; by analyzing the time-domain signal collected in the experiment, obtained the distribution of compressive stress in the layers of the foundation, the laminar stress curves approximate parabola, the vertex is the maximum compressive stress, that is, the maximum point of dynamic force. These conclusions are important theoretical basis for optimizing vibration parameters of roller and on-site construction.

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