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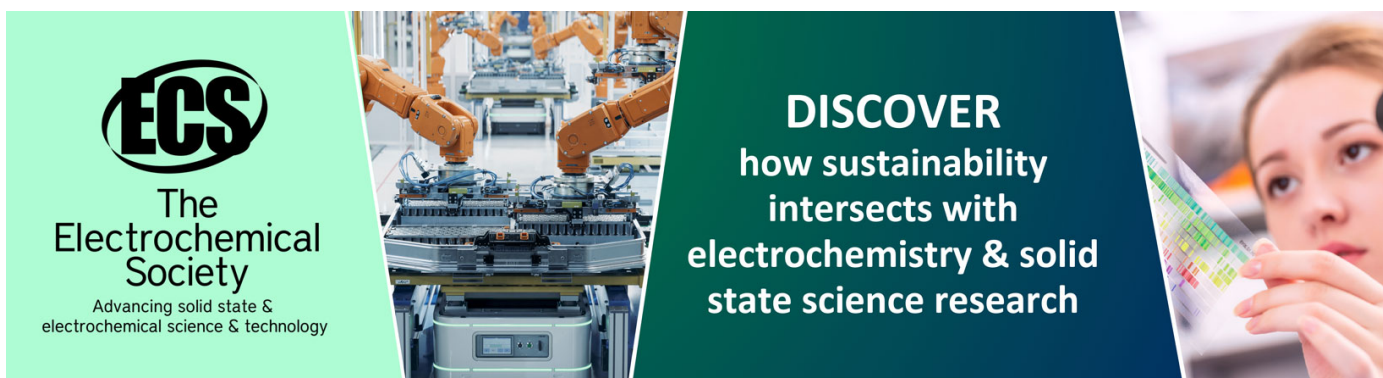
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Study on structural strength of paver screed based on finite element method

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Abstract. In order to ensure the rationality of screed structure design and reliability of structure strength, the structural finite element model of paver screed was established with the aid of APDL language. The static and dynamic characteristics of the screed are analysed based on the finite element method. Results show that maximum principal stress of screed in the bar is 113Mpa, maximum deformation is 1.82mm, the screed meets the normal demand both in intensity and rigidity. Natural frequencies and according vibration model of screed were obtained from finite element modal analysis, the first-order natural frequency in a vibrator adjustable frequency range, so working frequency should avoid the first-order natural frequency, and the change rule of strain and stress amplitudes of screed with the vibration frequency was obtained from harmonic response analysis. The structural static and dynamic analysis of screed provides the basis for the structure design and the adjustment of construction parameters.

1. Introduction

The screed, a main working equipment of the paver, is mainly used to transfer excitation force of vibrator to layer mat, obtaining paving and shaping mixture mat with a certain geometric size and compactness of the layer [1]. Moreover, screed keeps contact with layer mixture during vibration compaction and plays a buffer action on the force from road, and it ensures that the paver can work properly. Therefore, the rational design of the screed structure and the reliability of structural strength are of great significance to improve the paving quality and reduce the vibration and wear of the screed. Finite element analysis is used to simulate the displacement field, strain field, stress field and temperature field of the mechanical structure by numerical calculation. According to the above, the possible changes of structural performance and the possible defects in the design of mechanical structure are predicted. The finite element numerical analysis is an important method for the design and analysis of the mechanical structure because of its convenience, practicability and effectiveness. Finite element analysis is performed on the tamper and vibrator of the paver, but the static and kinetics analysis of the screed is seldom [2]. In reference [3], the response surface method was used to optimize the uniformity of the transverse amplitude on the screed, optimizing eccentric mass and eccentric distance of the vibrator, and improving the screed paving density uniformity. In reference [4], the relationship between deformation of the screed to the preload and the phase angle of the exciting shaft is studied, reducing the deformation of the screed.

In order to improve the rationality of structure design and the reliability of structure strength for screed, the screed of a paver as the research object, the modal analysis, harmonic response analysis and the strength stiffness checking are carried out based on the finite element method.



2. Structural analysis of screed

In order to facilitate the modeling, it is necessary to simplify the calculation model without affecting the analysis results. The structure of the bolt hole, fillet and bolt, which had little effect on the integral rigidity and strength of screed box, could be ignored. Using rigid entity instead of vibration axis and simplifying the coupling as rigid connection [5]. It mainly includes the 3 parts of the front processing, solving, post-processing by using the finite element software ANSYS to analyze the structure of screed. Selecting the solid element, the modulus of elasticity of structural material is 206GPa, Poisson's ratio is 0.28, and the density is 7800kg/m³. After free meshing, the finite element model of the screed is shown in Figure 1.

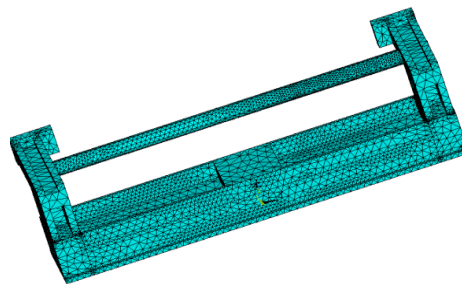
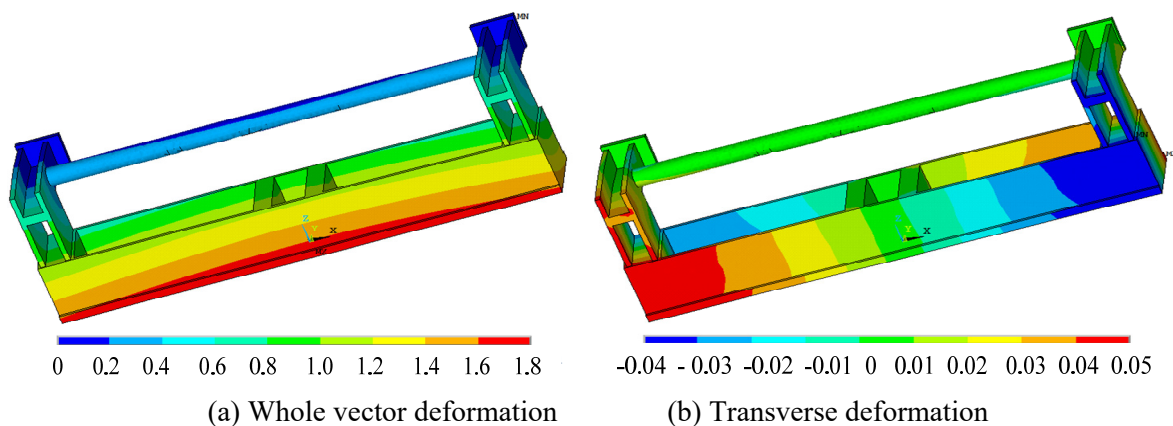


Figure 1. Meshing model of screed

The only two connections between the screed and the main body are in the position of the rear traction arm on both sides of the box and the main traction arm on the main body. According to actual installation of screed, adopt fixed constraint [6]. According to the test results, the longitudinal resistance force F acting on the screed is decomposed into vertical force $F_z=760\text{N}$ and vertical force $F_y=14600\text{N}$. They are applied to the 1/3 at the back end of the screed.

According to the above analysis, the force is applied load and displacement boundary conditions are processed, and the deformation of the screed structure is shown in Figure 2. Figure 2(a) is the whole vector deformation nephogram, the maximum deformation is 1.82mm. Figure 2(b) is the transverse deformation nephogram, the maximum deformation is 0.03 mm. Figure 2(c) is the longitudinal deformation nephogram, the maximum deformation is 1.58 mm. Figure 2(d) is vertical deformation nephogram, the maximum deformation is 0.90 mm. According to layer roughness transfer law, the stiffness of the three directions all meets the requirements and the greatest influence on the structural stiffness is the longitudinal deformation, so in the design of screed, the longitudinal stiffness should be enhanced.



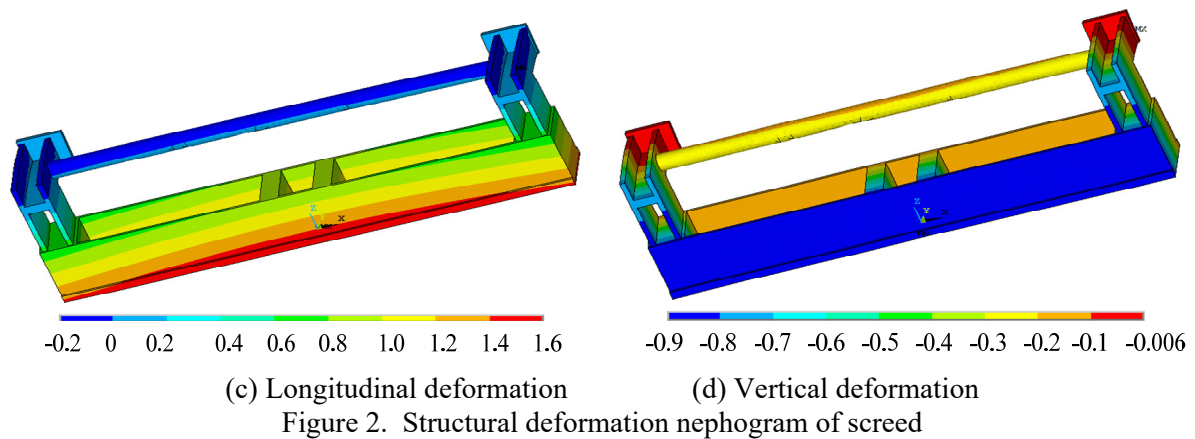


Figure 3 is before and after deformation of the screed which rotates around x axis. In the actual work, the angle cannot be too large, otherwise resulting unstable work of screed. Based on the finite element method, the boundary conditions are set, and the strength of the screed is analysed. The equivalent stress nephogram is shown in Figure 4, it shows that the stress in the position of the rear traction arm on both sides of the box and the main traction arm on the main body is larger, the maximum stress is 113MPa which is less than the yield strength of the material, the safety factor is 2 which is greater than the target value 1.3, therefore the strength meets requirement.

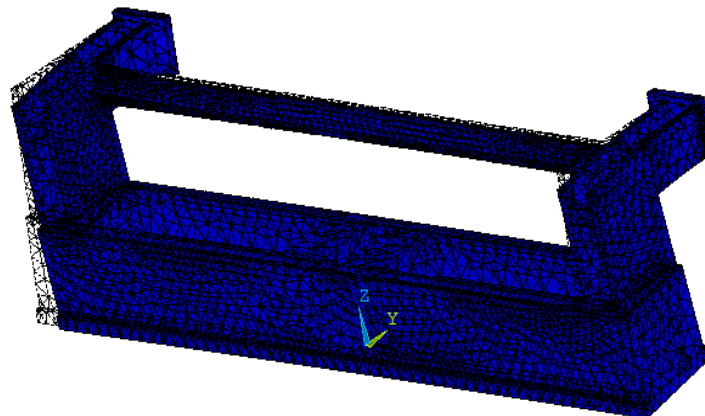


Figure 3. Screed deformation before and after

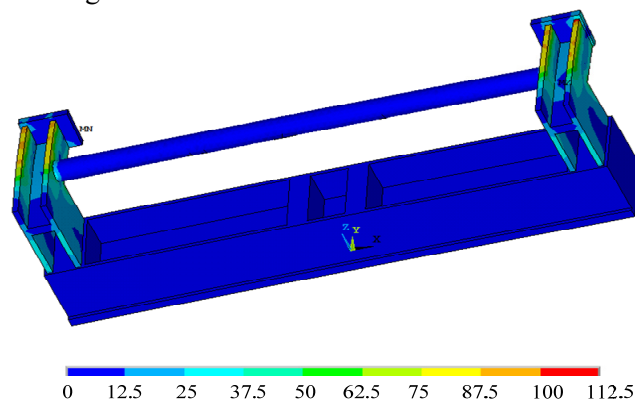


Figure 4. Equivalent stress nephogram of screed

3. Modal analysis of screed

There are 7 methods to extract the modal in ANSYS, including block lanczos method, subspace method, power dynamic method, reduced method, unsympathetic method, damped method, QR damped method [7]. Because the model adopts solid entity, and block lanczos calculation is accurate, the operation speed is fast, it also has a good processing ability to solid entity, so we use block lanczos method for modal analysis of screed.

The screed is a multiple-degree-of-freedom vibration system. The high order mode of the mechanical structure can be neglected in the vibration response of the system on the basis of vibration theory [8]. So the first 6 modes of the ironing plate are calculated, and the modal shapes corresponding to the 6 order natural frequencies are extracted. The results of the first 6 order modal analysis are shown in Table 1.

Table 1. The results of model analysis

Order	Natural frequency(Hz)	Mode shapes
1	34.78	Y Direction oscillation
2	59.10	X Direction oscillation
3	78.03	Y Direction bending
4	83.65	Z Direction bending
5	95.14	X Direction torsion
6	95.48	Y Direction torsion

4. Harmonic analysis of screed

In the process of working, the screed is subjected to external excitation. To analyse the dynamic response of the ironing plate at different frequencies, the harmonic response analysis is performed. The steady-state response of screed structure under harmonic excitation is obtained to continuously predict the dynamic characteristics of the system, so as to verify whether the structure can overcome the other adverse effects caused by resonance, fatigue and forced vibration.

Based on the theory of vibration mechanics, the steady-state vibration response of the formula is obtained. Then, the differential equations are decoupled and converted to a single degree of freedom system by using canonical coordinate transformation. Next, the steady state response of the system under canonical coordinate system is obtained, as shown in formula (1). Finally, the steady state response of the system under the original generalized coordinate system can be obtained by inverse coordinate transformation.

$$x_{pi} = \frac{F_{pi}}{K_{pi}} \frac{1}{\sqrt{\left((1-z_i^2)^2 + (2\delta_i z_i)^2\right)}} \sin(\omega t - \psi_i) \quad (i=1, 2, \dots, 6) \quad (1)$$

$$\text{Command: } z_i = 3\pi f / \omega_i, \delta_i = \frac{\tilde{C}_{pi}}{2\sqrt{K_{pi}}\sqrt{M_{pi}}}, \psi_i = \arctan \frac{2\delta_i z_i}{1-z_i^2}.$$

Where: F_{pi} is Generalized exciting force corresponding to the i th regular coordinates; K_{pi} is the i th diagonal elements of the principal stiffness matrix; z_i is frequency ratio; δ_i is damping ratio; ψ_i is the phase difference between the steady state response and the exciting force; f is the external excitation frequency; ω_i is the i th natural frequency of screed obtained by modal analysis.

When using the full method to analyse the harmonic response of the screed, the constraint boundary condition is consistent with the modal analysis. According to the natural frequency of the modal analysis and excitation frequency range, the minimum frequency and the maximum frequency of the harmonic response analysis are 0Hz and 200Hz respectively. At the same time, the steady force of 2500N is applied to bottom of the screed along the negative direction of the Z axis. The maximum

displacement nodes and the maximum stress node are selected in ANSYS, also the corresponding amplitude and stress. The curves of amplitude and stress vary with frequency as shown in Figure 5 and Figure 6, respectively.

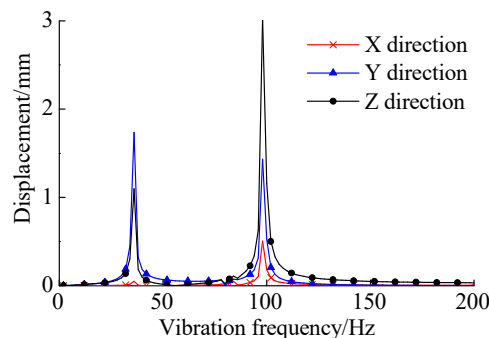


Figure 5. Displacement-frequency curve

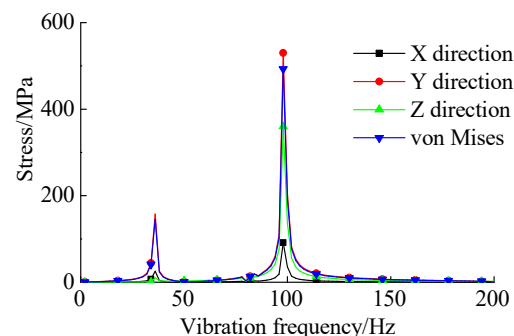


Figure 6. Stress-frequency curve

Figure 5 shows that there are 2 peak points in the displacement of screed and the corresponding vibration frequencies are the first and the sixth order natural frequencies, respectively. The amplitude increases sharply and then decline to smooth when the vibration frequency through the first order natural frequency. The amplitude is once again reached a peak when frequency passes the sixth order natural frequency. From the comparison of displacement-frequency curves in different directions, the amplitude of the Y direction is relatively large, which is easy to cause the transverse uneven of screed amplitude, so the transverse stiffness of screed should be strengthened in the design. Figure 6 shows that stress of the screed is less than allowable stress. The stress of screed in the Y direction is the biggest, which is the main stress component of the equivalent stress. When the vibration frequency is beyond the first order natural frequency, the stress change is relatively stable and 40~55Hz is an ideal excitation frequency range. Therefore, in order to improve the stability of the screed, avoid resonance and ensure the layer with a certain compacted strength from screed, the vibration frequency should be avoided in the vicinity of the natural frequency of screed and adjust the excitation frequency is greater than the natural frequency of screed.

5. Conclusion

Through the analysis of the static and dynamic analysis of a screed, the following conclusions are obtained. The finite element model of the screed is established, and the structure design meets the requirement through static analysis. The stiffness of the position with larger deformation can be enhanced properly, and the material of the position with lower stress can be reduced. It reduces the cost and provides the reference for the optimal design of screed. Based on modal analysis and harmonic response analysis, the change of the low order natural frequency, the vibration response displacement and the stress amplitude of screed with the excitation frequency are obtained. The exciting frequency should be as far as possible avoided the resonance frequency and the frequency range that the amplitude of displacement and stress is larger. During the design, finite element static analysis combined with the modal analysis and harmonic response analysis can be used to predict the weak parts of the screed. The above analyses provide the reasonable design for the screed structure and the basis for the selection of construction parameters.

Acknowledgments

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