Analysis of Factors Influencing Mechanical Properties of Corrugated Steel Based on Entropy Method

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Received 30 November 2022; Accepted 27 December 2022;
Publication 06 February 2023

Abstract

In recent years, corrugated steel has been used in some domestic tunnel construction for its large section and high strength, and has become a new type of tunnel support structure. Corrugated steel mechanical properties will directly affect the stability of support structure. Therefore, the important thing is to choose the appropriate parameter to improve the mechanical performance of ripples. Parameters that affecting the mechanical properties of corrugated steel include wave height, corrugation thickness and wave distance. This massage will rely on the Qipan Mountain tunnel project, studying its fabricated corrugated steel supporting structure, and selects corrugated steel with different thicknesses, wave heights and corrugated spans for transient analysis. The largest deformation of corrugated steel under blasting shock is calculated by numerical simulation to react the corrugated steel mechanical properties, and then use the method of Entropy to determine the influence of different parameter values on mechanical performance of corrugated steel.

European Journal of Computational Mechanics, Vol. 31_4, 539–554.
doi: 10.13052/ejcm2642-2085.3144

The weight coefficient of wave thickness is 92.38%, the influence weight coefficient of wave height is 7.54%, and the influence weight coefficient of wave short is 0.07%. It is shows that the thickness has the greatest influence on the mechanical properties of the supporting structure, and the wave distance has no influence. Through the above analysis, the parameter design and stability design of corrugated steel support structure can be given some reference and help.

Keywords: Parameter analysis, corrugated steel support, transient response, numerical simulation, the entropy method.

1 Background

In recent years, with the continuous improvement of our national economic level and the continuous implementation of traffic construction in the western mountain areas, the mountain road tunnel construction has achieved rapid development. It is essential to complete the initial support timely to control the structural deformation of surrounding rock during tunnel excavation. Although the traditional steel and shotcrete support structure has a fast forming speed and good effect on controlling the deformation of surrounding rock, there are also some defects, such as not easy to compact and easy to crack at the joint when the concrete is sprayed behind the steel.

Based on the above problems, the engineer proposed a new type of tunnel initial support structure, which is composed by corrugated steel, and its structure form is shown in Figure 1. The characteristic of such support structure is that the corrugated steel is connected by bolts in both the ring and the longitudinal connection. It has the characteristics of convenient installation, easy transportation, good bonding ability between the back and concrete, which will ensure the compactness of the concrete structure, can effectively alleviate the above shortcomings, and the use of arc support can greatly improve the mechanical strength of the arc arch. At present, with the improvement of the economic level and the implementation of the traffic conditions in western China, the mountain road tunnel construction has achieved rapid development. The initial support should be completed in time to control the structural deformation of surrounding rock during tunnel excavation. Although the traditional steel with bolt-shotcrete support structure has rapid shaping and good effect in controlling the deformation of surrounding rock, it is also prone to lack of filling such as not easy compaction and easy cracking at the joint when the concrete is sprayed behind the steel.

Figure 1 Corrugated steel form.

Nowadays, scientists have carried out some studies on the structure of the connecting part of corrugated steel. For example, Sun Keguo [1, 2] using ANSYS to analyze the variation trend of the bearing capacity of corrugated plate structure under different thicknesses and loads, then analyzed the mechanical characteristics of the inner and outer peaks and troughs of corrugated plate. Li Shufan used [3] MIDAS/GTS-NX to calculate the corrugated steel structure used as the initial tunnel support structure, and analyzed its engineering feasibility from the perspective of mechanics. Huang Mingli studied the structural strain, bolt axial force, structural deflection and bending stiffness of butt flat flange joints [4], back reinforced flange joints and lapping joints, and finally found that the initial stiffness of the three kinds of flange joints was different. Chen Tianli [5] The buckling of flat section of corrugated steel is studied, and the corresponding theoretical formula is obtained, which provides reference for the subsequent engineering application. Sun Xibo [6] with the tunnel of Nanyan College Bridge Station of Changping Line of Beijing Metro as the background, the settlement and deformation of corrugated steel support structure under local working conditions are analyzed by numerical simulation method, which indicates the feasibility of corrugated steel structure in subway tunnel construction. Fengzhi Wang [7] proposed a new linkage structure of replaceable corrugated steel plate (CSP), and 11 different sample models are established. It is verified that the yield lateral load and initial stiffness are mainly affected by the CSP aspect ratio. On the

other hand, peak level loading, ductility and energy consumption are closely related to the depth ratio and aspect ratio of waves. Liu Tianzheng [8] through the measures of thickening flange joint plate and applying square steel pipe, the flexural capacity of corrugated steel plate is effectively improved.

Compared with traditional steel arch structure [9], corrugated steel structure has more outstanding advantages in service performance. In order to better meet the needs of the use of corrugated steel initial support in the engineering field, corrugated steel mechanical propertirs with different parameters have been studied. It has important application value and practical significance to the application of corrugated steel supporting structure in tunnel engineering. Based on the prefabricated corrugated steel supporting structure of Qipanshan tunnel [10], this paper applies the corresponding transient load by changing the thickness, wave height and wave distance of the steel plate. In order to study corrugated steel mechanical properties, the largest deformation of corrugated steel plate under different parameters was analyzed by numerical simulation. Entropy method was used to analysis the data obtained under different parameters, and the influence weight coefficient of the three parameters on the mechanical properties of corrugated steel was obtained, so as to analysis the influence of the three parameters on corrugated steel mechanical properties. This study can provide some theoretical basis for parameter selection of similar corrugated steel in later periods. At the same time, compared with the traditional experimental method, numerical simulation greatly reduces the cost and improves the safety of the experiment.

2 Model Parameters

By referring to relevant materials, and relying on the Chengjiang Expressway Qipanshan Tunnel project in Yunnan Province [10], the supporting section of corrugated steel is determined to be cosine-like corrugated, and the waveform formula of corrugated steel is shown in (1).

$$Y = 70 \times \cos\left(\left(2 \times \frac{\pi}{380}\right) \times x\right) + 85 \tag{1}$$

The wave height is 140 mm, the steel plate thickness is 5 mm, and the wave distance is 380 mm. 20 mm bolts are used to connect the annular and longitudinal directions, and the flange thickness is 9 mm. The corrugated steel structure is finally obtained by Solidworks, as is shown in Figure 2.

Through access to information, the Q235 steel corrugated steel materials are used in projects, parameters of the material as shown in Table 1.

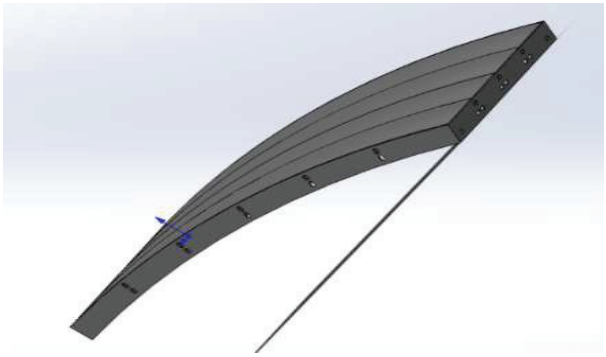

Figure 2 Corrugated steel model.

Table 1 Parameters of Q235 steel

Density	Young's Modulus	Poisson's Ratio	The Yield Strength	Damping Ratio
7850 kg/m^3	206GPa	0.3	235MPa	0.006

3 Numerical Analysis and Results

This paper aims at reflecting the mechanical properties of corrugated steel structure through the maximum deformation of corrugated steel under transient load, and its working principle is shown in (2)

$$Y_{max} = 5ql^4/384EI \tag{2}$$

Where q means the uniformly distributed load size, l means the specimen length, E means the elastic modulus of the material, I means the moment of inertia of the section of the specimen.

3.1 Applied Load Condition

In the actual process of tunnel construction, the deformation of the supporting structure is mainly caused by the shock wave generated in the blasting construction. Therefore, this paper intends to use blasting shock wave as the input load to analyze the corrugated steel structure.

As a special form of load, blasting has the characteristics of short action time, large action peak and attenuation with distance compared with other forms of load. This research shows that [11, 12] the blasting shock wave has two stages. First is rising stage. The shock wave rises rapidly in a short time and reaches the maximum positive pressure, and then gradually decays

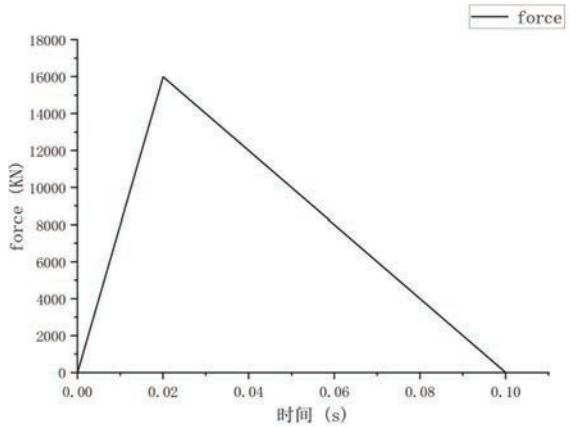

Figure 3 Diagram of load.

to 0, at which time the positive pressure ends. Then the shock wave will become negative and decay to 0 again after acting for a period of time, at which time the blasting impact effect is over. Since the maximum value in the positive pressure stage is much greater than that in the negative pressure stage, people generally pay attention to the process of positive pressure, and the process of negative pressure stage is negligible.

In practical engineering calculation, there are two ways to simplify the load, one is to simplify the input waveform of the exponential function, the other is to simplify the action waveform of the primary function, in which the exponential function waveform is mostly used in the study of single hole. The primary function waveform is mainly used for the model calculation with high complexity, and can better ensure the accuracy of calculation Degrees.

In this paper, the impact generated by a tunnel excavation blasting in Chongqing is used as the normal input load [13], and its waveform is shown in Figure 3. The loading time of the load is 0.02 s, and the total acting time is about 0.1 s.

According to the above load conditions, the load as shown in Figure 3 is applied to the upper surface, and the direction is along the normal direction of corrugated steel, the direction is downward. Fixed constraints are applied to the flange on both sides of corrugated steel. The two plates are connected by bolts with a diameter of 20 mm, and surface contact is adopted. The obtained finite element pre-treatment model is shown in Figure 4.

Through the result identification of the simulation result cloud map, it can be found that the maximum deformation of the model is at the middle point

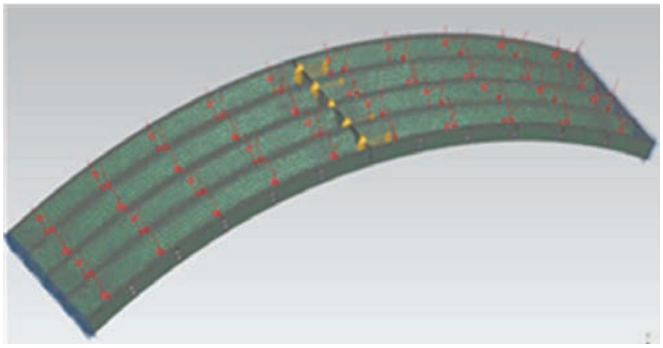

Figure 4 FEM model.

Table 2 Parameters of different wave height

Test Group	Model Parameters (l-h-b)
1	380-140-5
2	380-160-5
3	380-170-5
4	380-180-5

of the flange connecting the two steel plates, so this point is selected as the value point of this test.

The following is to carry out experiments by selecting different values of three parameters of corrugated steel, namely wave height, wave thickness and wave distance, and analyze the obtained results.

3.2 Analysis of Different Wave Heights

Change the high wave height of the wave pattern, and then determine its impact on the mechanical properties of ripples. First, create four groups of models. Then, by applying the load to observe the maximum displacement at the duty point, as shown in Figure 4. The smaller the value, the better the stability of corrugated steel under load impact, and the better its mechanical properties. The selection of four groups of model parameters is shown in Table 2.

In this table, l means the wave distance of corrugated steel, h means the height of corrugated, b means the thickness of plate. this part changes the wave height of corrugated steel h.

By applying load to the above model, the conclusion shown in Figures 5, 6, 7, 8 can be obtained. The results of the study are shown in Table 3.

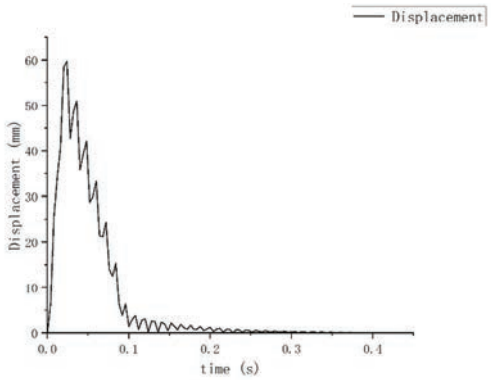

Figure 5 380-140-5.

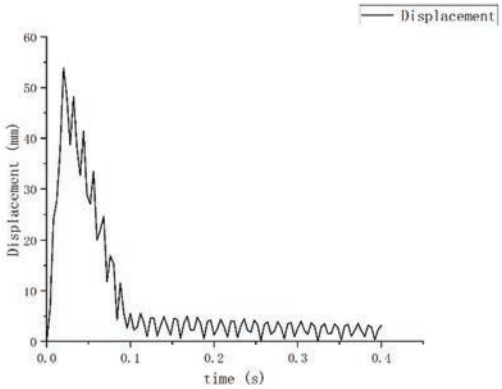

Figure 6 380-160-5.

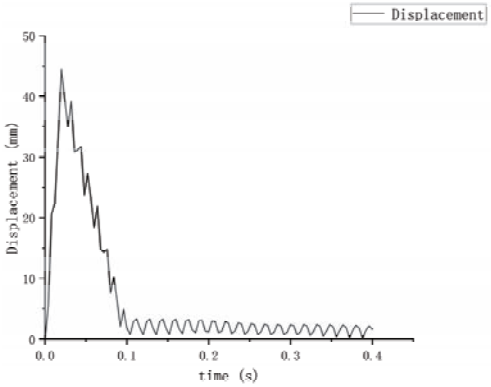

Figure 7 380-170-5.

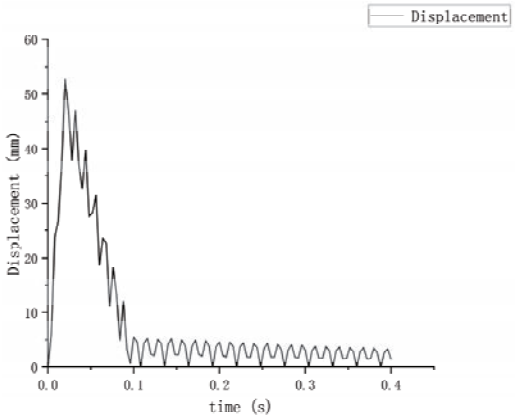

Figure 8 380-180-5.

Table 3 Maximum displacement at different wave heights

Model Parameters	380-140-5	380-160-5	380-170-5	380-180-5
D_m/mm	60.45	53.91	52.68	44.55

Table 4 Model parameters

Group Number	Model Number (l-h-b)
1	380-140-5
2	380-140-7
3	380-140-9

Observing the four waveforms, it can be seen that when the wave height is 140 mm, the maximum displacement of the observation point is 60.45 mm, which is also the largest among the four groups of data. When the wave height is 180 mm, the minimum displacement is 44.55 mm, and the maximum deformation is reduced by 26%. Therefore, increasing the height of corrugated can improve the mechanical properties of corrugated steel.

3.3 Analysis of Different Wave Thicknesses

The influence of thickness on corrugated steel mechanical property was studied by changing the thickness of corrugated steel with other parameters unchanged, and the maximum displacement of corrugated steel was observed. The smaller the value, the better the stability and mechanical properties of corrugated steel under blasting impact. The parameters of the model are shown in Table 4.

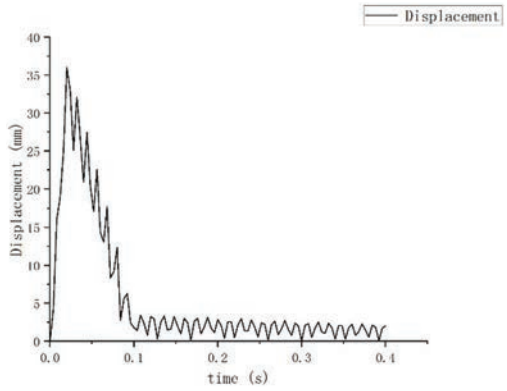

Figure 9 380-140-7.

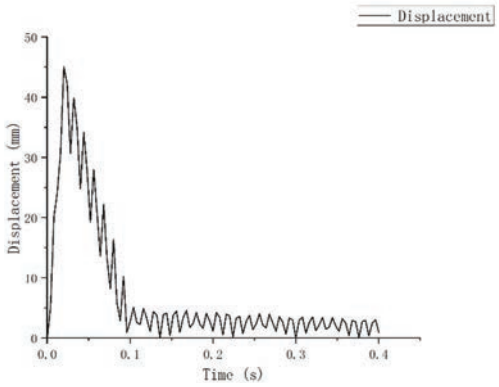

Figure 10 380-140-9.

Table 5 Maximum displacement at different thicknesses

Model Parameters	380-140-5	380-140-7	380-140-9
D_m /mm	60.45	45.05	35.98

By changing the thickness of steel plate, three types of corrugated steel plates of 5 mm, 7 mm and 9 mm were selected for research. After applying load to the model, the response curve obtained was shown in Figures 5, 9, 10, and summarized as the results shown in Table 5.

According to the deformation of three kinds of steel plate with different thickness, it can be seen that the thickness of steel plate has an obvious influence on its displacement. The maximum displacement of the observation point is 35.98 mm when the thickness is 9 mm, while the maximum

Table 6 Model parameters

Group Number	Model Number (l-h-b)
1	360-140-5
2	380-140-5
3	400-140-5

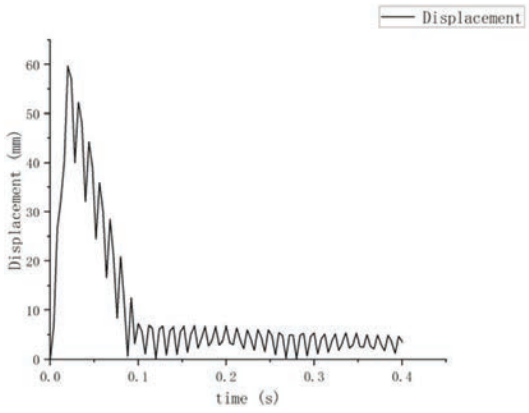

Figure 11 360-140-5.

displacement of the observation point is 60.45 mm when the thickness is 5 mm, which is 40.5% less than that when the thickness of the steel plate is 5 mm. Through the above calculation, it is obvious that increasing the thickness of corrugated steel plate can significantly reduce its deformation. In practical application, it is preferred to increase the thickness of the plate to improve stability of the structure.

3.4 Analysis of Different Wave Distances

In this part, corrugated steel mechanical properties under different wave pitch are studied by keeping the thickness of steel plate and the height of ripple unchanged and changing the wave pitch. The test model parameters are shown in Table 6.

Through the above three types of corrugated steel plate applied the above mentioned load, observe the maximum displacement of the steel plate under the load. The smaller the displacement is, the stronger the stability of corrugated steel structure, the better its mechanical properties.

After the analysis, the displacement of three types of corrugated steel is shown in Figures 5, 11 and 12.

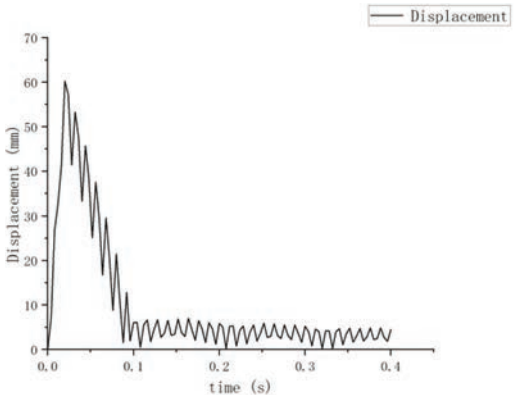

Figure 12 400-140-5.

Results are summarized in Table 7:

Table 7 Maximum displacements at different wave distances

Model Parameters	360-140-5	380-140-5	400-140-5
D_m /mm	59.61	60.45	60.27

Through the above calculation results, the maximum deformation of corrugated steel plate under different wave pitch can be obtained. It can be seen from the calculation result figure that the displacement reaches the maximum value at 0.02 s. When the wave distance is 360 mm, the maximum deformation of steel plate is 59.61 mm. When the wave distance is 380 mm, the maximum deformation is 60.45 mm. When the wave distance is 400 mm, the maximum deformation is 60.27 mm. It can be seen from the above calculation results that the maximum deformation of steel plate does not change with the change of wave distance. Therefore, it can be concluded that the mechanical properties of corrugated steel are independent of the corrugated distance.

4 Result Evaluation

By calculating the maximum deformation of different types of corrugated steel plate, the influence of three main parameters of corrugated steel on its mechanical properties is qualitatively analyzed. In order to obtain the influence degree of the three parameters, it is also necessary to determine the respective influence weight coefficients of the three parameters. In this paper,

the weight of the above three factors will be calculated by using the method of Entropy Value. It is an objective empowerment method that determines the weight of the indicators according to the size of their observations. For an indicator, the greater the difference in observations in the indicator, that is, the greater the entropy of the indicator information, the greater the impact of the indicator on the system, if the smaller the change of observations in the indicator and the smaller the entropy of the indicator information, the smaller the impact of the indicator on the system [14].

Therefore, using this tool, we can provide a basis for comprehensive evaluation of multiple indicators.

The steps of entropy method are generally summarized as follows:

(1) Organize the data to be processed into a matrix of i*j;
(2) non-negative processing of the data in the matrix;
(3) Calculate the proportion of the ith scheme under the jth index, and the calculation formula is shown in (3)

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{3}$$

(4) For the entropy value of the ith index, its calculation formula is shown in (4).

$$e_j = -k \sum_{i=1}^{n} p_{ij} \ln(p_{ij}) \tag{4}$$

With k = 1/lnm;

(5) Calculate the difference coefficient of the g_j. The larger the difference coefficient is, the greater the influence on the index is, and the smaller the entropy value is. The calculation formula is shown in (5).

$$g_j = 1 - e_j \tag{5}$$

(6) Calculate the weight w_j, as shown in Equation (6).

$$w_j = \frac{g_j}{\sum_{j=1}^{m} g_j} \quad j = 1, 2, \ldots, m \tag{6}$$

(7) Calculate the comprehensive score of each program s_i, as shown in (7).

$$s_{i=} \sum_{j=1}^{m} w_j * x_{ij} \tag{7}$$

The entropy method determines the weight of indicators according to the difference and change of each index value. It is an objective weight method, which can effectively avoid the intervention of human factors.

On the basis of the above theory, this paper uses SPSSAU software to analyze the simulation data, and the results are shown in Table 8:

Table 8 Weight analysis results of all factors

Parameters	Entropy Value of Index e_j	Valid Value of Index g_j	Weight Coefficient w_j
Wave heights	0.9983	0.0017	7.54%
Wave thicknesses	0.9793	0.0207	92.38%
Wave distances	1.0000	0.0000	0.07%

It can be seen from the calculation results that the influence weight coefficient of the thickness of corrugated steel plate is 92.38%, which is much higher than the influence weight coefficient of the ripple height and wave distance of corrugated steel plate. The weight coefficient of wave distance is only 0.07%. From the engineering perspective, it can be understood that the wave distance has almost no influence on the mechanical properties of corrugated steel plate.

5 Conclusion

In this paper, finite element numerical analysis method is used to analyze the transient response of prefabricated corrugated steel under blasting impact based on the Qipanshan tunnel project of Chengjiang Expressway in Yunnan province, and the following conclusions are drawn:

(1) In view of the corrugated steel plate wave height, wave, wave from three parameters is analyzed, by applying the same load, analysis of different types of steel plate under the same load maximum deformation reflect the performance of the steel plate, analysis of wave height and wave height had effect on the mechanical property of corrugated steel sheet, the influence of wave from almost negligible.

(2) The entropy method was used to calculate the weight coefficients of three parameters on the mechanical properties of corrugated steel. The weight coefficients of wave thickness, wave height and wave distance were 92.38%, 7.54% and 0.07%. It can be concluded that the most important factor affecting the mechanical properties of corrugated steel is the wave thickness, followed by the wave height. In the design

process, we should focus on the analysis of the thickness, combined with the cost and other factors comprehensive analysis, to select the optimal results.

(3) The main deformation position of the prefabricated corrugated steel structure is at the flange plate, so in the actual construction, the bolt connection part of the flange plate should pay attention to the construction quality, to ensure that the later construction can be carried out normally.

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Biography

Wang Taiheng received his bachelor's degree in Mechanical Design, Manufacturing and Automation from Hefei University of Technology in 2018, and was admitted by Southwest Forestry University in 2020. He is currently studying for his master's degree in Mechanical Manufacturing and Automation from Southwest Forestry University. His research areas are CAE simulation, structural shock and response.