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# Finite Element Analysis and Structural Performance Research on Chassis Frame of Crawler Bamboo Transport Vehicle

Bin Xu[1,*], Xue Zhang[1], Weibo Gong[2]

[1] Department of Mechanical Engineering, Xihua University, Chengdu, 610039, China

[2] Department of Aerospace and Intelligent Equipment, Xihua University, Chengdu 610039, China

*Corresponding author: Bin Xu (Email: 2605425860@qq.com)

## Abstract

**Because most of the bamboo forests in China are distributed in hilly areas, the terrain conditions are complex, and the transfer of bamboo skidding is difficult. In view of the above problems, a forest multi-functional power platform was developed. In order to ensure the safety of the whole chassis frame structure design of the power platform and understand the vibration characteristics of the whole chassis frame, the chassis frame of the tracked transport vehicle is taken as the research object. Firstly, the three-dimensional model of the chassis frame is established in SolidWorks software. Based on HyperMesh, the finite element model of the frame is established. Combined with two typical working conditions of full load and half load, the static and modal analysis is carried out by OptiStruct. The stress and deformation distribution of the frame under different working conditions are obtained. The results show that the maximum stresses of the frame under full load and half load conditions are 172.6 MPa and 206.1 MPa, respectively, which are less than the yield limit of the material, and the maximum deformation meets the allowable requirements. The modal analysis results show that the natural frequency of the frame does not coincide with the excitation frequency of the road surface and the engine, and there is no resonance risk. The results show that the frame structure meets the requirements of strength and stiffness.**

## Keywords

**Track Transport Vehicle; Chassis Frame; Finite Element Analysis; Modal Analysis.**

## 1. Introduction

Bamboo is a gramineous plant with short growth cycle and strong renewable ability. It is an important green biological resource[1,2]. China is rich in bamboo resources, and the area and yield of bamboo forest are among the highest in the world[3]. However, more than half of the bamboo forests are distributed in the southern hills and mountains[4]. Due to the limitation of terrain conditions, the process of bamboo harvesting and transportation is faced with problems such as transportation difficulties and low efficiency. In order to adapt to the complex forest environment, tracked transport equipment is widely used in bamboo transport operations because of its good trafficability and adhesion performance.

Aiming at the demand of bamboo transportation, a crawler truck was developed to provide different transportation modes for different kinds of bamboo. For clustered bamboo, it can be directly placed on the car body for full-load transportation, while for longer bamboo, it can be transported by half-load traction. The load forms under the two transportation modes are significantly different. Especially under the half-load transportation condition, the load is asymmetrically distributed, and

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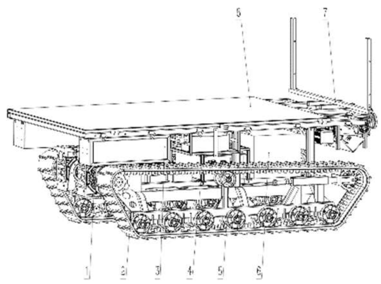
the impact and vibration caused by the slope driving make the stress state of the frame complex and changeable. As the key bearing structure of the whole machine, the chassis frame not only bears all the loads and excitations of the machine, but also is directly related to the structural safety and operation stability of the whole machine[5]. In this paper, Hypermesh finite element simulation software is used to carry out finite element analysis on the chassis frame of the whole machine to ensure the safety and stability of the whole vehicle in operation.

## 2. The Structure and Working Principle of the Whole Machine

### 2.1 Overall Structure

As shown in Figure 1, the tracked vehicle is mainly composed of a chassis frame, a drive unit, a crawler walking mechanism, a half-load bearing assembly, a through-type delivery platform, an electric control box, a battery, and a range extender. The main design indexes of the whole machine are shown in Table 1.



1. Drive unit 2. Chassis frame 3. Electric control box 4. Track walking mechanism 5. Battery 6. Extender 7. Semi-loaded skidding assembly 8. Through delivery platform

**Figure 1.** Three-dimensional model of chassis frame

**Table 1.** Main technical parameters

| Parameters | Numerical value |
| --- | --- |
| **The overall dimensions of the machine（mm*mm*mm)** | 3000*1800*1000 |
| **No-load mass (kg)** | 1590 |
| **Full-load transport skidding volume (kg)** | 500 |
| **Semi-loaded transport skidding volume (kg)** | 350 |
| **Maximum speed (m/s)** | 0.5 |

### 2.2 Working Principle

The track transport vehicle adopts the upper and lower double-layer frame structure. The driving units are arranged on both sides of the front end of the lower frame, which are connected with the driving wheels of the crawler walking mechanism, so as to drive the crawler to realize the whole machine walking. Key electronic components such as range extender, battery and motor driver are arranged in the lower frame to improve the transportation capacity of the upper frame. The mechanical connection between the upper and lower frames is used to facilitate the maintenance of the components of the lower frame. The functional structures such as storage boxes and external discharge interfaces are reserved below the upper frame.

The power platform provides different modes of transportation according to the different types of bamboo. For bamboo, the half-load skidding transportation mode is adopted, that is, one end of the bamboo is supported by the half-load skidding component, and the other end is slipped anywhere, as shown in Figure 2. For cluster bamboo, it is directly placed on the through platform for full-load transportation.

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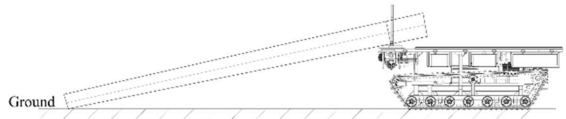
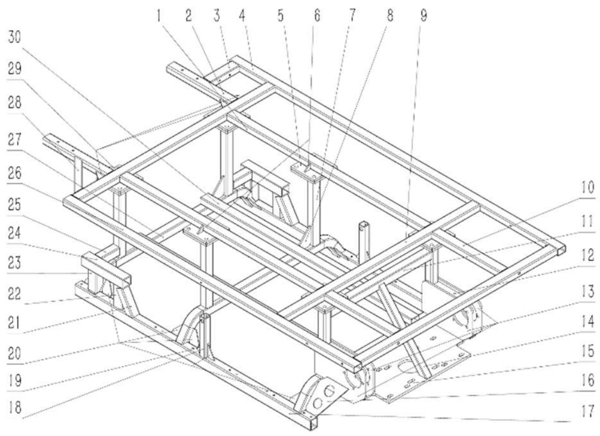



**Figure 2.** Schematic diagram of half-load transportation state of power platform

# 3. Finite Element Model of Chassis Frame

## 3.1 Establishment of Parametric Model of Chassis Frame

The parametric model of the chassis frame is established in the three-dimensional software Solidworks, as shown in Figure 3. The chassis frame is mainly composed of multiple beams, stiffeners and connecting plates. The material used is Q235, the elastic modulus is 2.10 × 105MPa, the Poisson 's ratio is 0.30, and the density is 7.85g / $cm^3$.




1 ) Upper frame reinforced longitudinal beam-long 2 ) skidding component installation longitudinal beam 3) Hand rocking reducer installation beam 4) Upper frame outer longitudinal beam 1 5) frame connecting plate 6) Frame connecting plate stiffeners 7) Upper frame support tube 8) Support tube reinforced triangular plate 9) Upper frame crossbeam 10) Upper frame reinforced longitudinal beam-short 11) Strengthen the horizontal tube 12) Drive support reinforcing plate 13) Drive support mounting plate 14) The drive unit supports the reinforced pull arm 15) Drive unit support plate 16) Drive support stiffeners 17) The supporting wheel installs the rectangular pipe 18) Bracket wheel installation pipe 19) Installation of reinforcing ribs for supporting pulley 20) The bow beam strengthens the triangular plate 21) Strengthened channel steel 22) Tightening support tube 23) Support channel steel 24) Tension wheel installation square tube 25) Strengthen square tube 26) Upper frame outer longitudinal beam 2 27) Underframe bow beam 28) Lumber assembly reinforcing tube 29) Strengthened triangular plate 30) Bottom frame longitudinal beam

**Figure 3.** Three-dimensional model of chassis frame

## 3.2 Construction of Finite Element Model of Chassis Frame

The three-dimensional model of the frame is imported into Hypermesh for finite element modeling. In order to improve the efficiency of the simulation and the accuracy of the results, the rounded corners and chamfers that have little effect on the simulation results are cleaned up[6,7]. The main structure of the frame is a thin-walled structure, so the method of extracting the middle surface is selected to divide the Shell mesh, and the shell element is used instead of the solid element to further improve the efficiency of the analysis. According to the model size, the grid size is set to 5mm.After division, the total number of grids is 376407, and the total number of nodes is 382522. The connection mode of chassis frame mainly adopts welding and bolt connection. The welding connection between components is equivalently replaced by RBE2 rigid unit. The bolt connection is simulated by Bolt command, and the type is Rigid[8]. The finite element model of the frame is shown in Figure 4.

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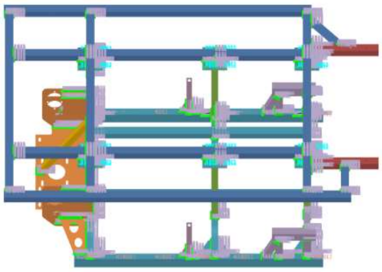

**Figure 4.** Frame finite element model

### 3.3 Load Conditions and Boundary Conditions

In the full-load transportation mode, the bamboo is completely placed on the transport vehicle, and its transportation load directly acts on the longitudinal beam and beam structure on the upper frame, and diffuses to the underframe structure through the upper frame. The maximum single skidding capacity of full-load transportation is 500 kg.

In the half-load transportation mode, the large end of the bamboo is mounted on the skidding component. The load generated during the transportation process first acts on the skidding component and is transmitted to the upper frame structure through the skidding component installation longitudinal beam. The maximum transportation load at the support position under the half-load transportation condition is 1.872Q (Q is the total weight of transporting bamboo).

In addition, the chassis frame also bears the self-weight load of each functional accessory during the operation process, including the drive unit, the battery, the upper frame cover of the range extender, the electric control box, the electronic control element and the skidding assembly. In addition, the analysis also needs to consider the internal stress caused by the weight of the chassis frame, and the gravity field with 9.8 m / s acceleration is set in the analysis.

When the driving road is uneven or the speed changes, some impact loads will be caused. These impact loads on the frame are dynamic loads. It is different from the size of the static load, but the load distribution is the same. Therefore, in the finite element analysis of the frame, the dynamic factors need to be taken into account. The dynamic load coefficient is introduced to correct each load, and the dynamic load coefficient is 2[9,10].

The chassis frame is supported and installed on the track by the supporting wheels on the left and right sides, so the degree of freedom on both sides of the chassis frame is constrained to simulate the actual support state of the vehicle and the ground.

## 4. Static Finite Element Analysis of Chassis Frame

### 4.1 Finite Element Analysis of Full-load Transport Conditions

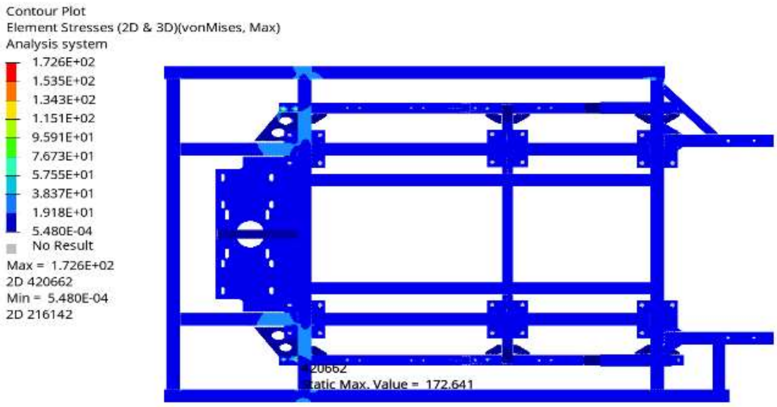


**Figure 5.** Equivalent stress cloud diagram of frame under full load transportation condition

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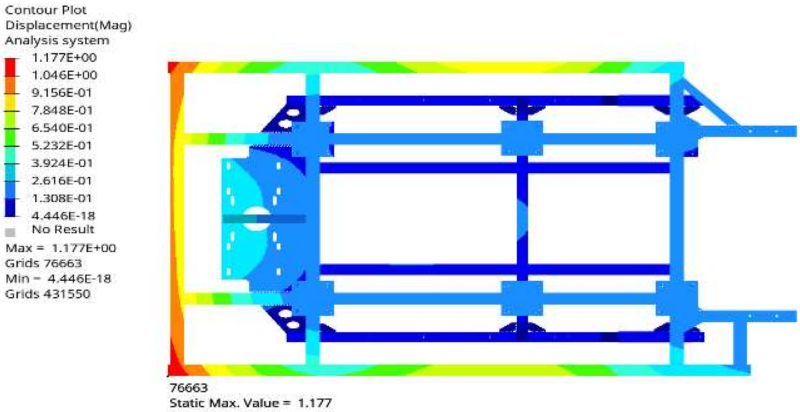


**Figure 6.** Displacement cloud diagram of frame under full load transportation condition

On the basis of the construction of the finite element model of the frame, the boundary conditions are applied according to the actual stress of the frame under the full-load transportation condition, and the OptiStruct solver is used to solve the finite element calculation of the chassis frame. The equivalent stress cloud diagram and displacement cloud diagram of the frame are obtained, as shown in Figure 5 and Figure 6, respectively.

It can be seen from the stress and displacement cloud diagram that under the condition of full-load transportation, the overall stress level of the frame is low and evenly distributed, and the maximum stress appears at the connection between the moment tube and the bolt installed on the supporting wheel. This area is the concentrated part of the constraint and load transfer, and there is a certain stress concentration, but the value is 172.6 MPa, which is lower than the yield limit of the material. The maximum displacement occurs at the left end of the frame. Due to the relatively small support at this place, large deformation occurs under load. The maximum deformation is 1.18 mm, which is less than the allowable value of 5 mm, which meets the requirements of structural use.

## 4.2 Finite Element Analysis of Half-load Transportation Condition

The OptiStruct module is used to solve the stress of the chassis frame under half-load transportation conditions. The obtained equivalent stress cloud diagram and displacement cloud diagram are shown in Figure7 and Figure 8, respectively.

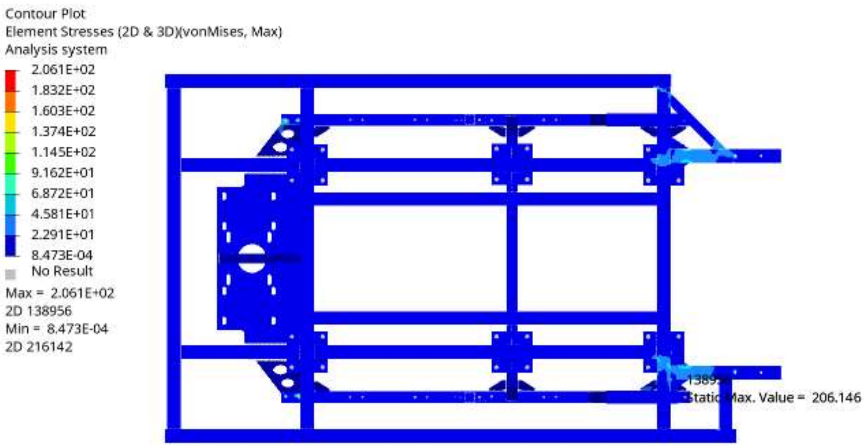


**Figure 7.** Frame stress cloud diagram of half load transportation condition

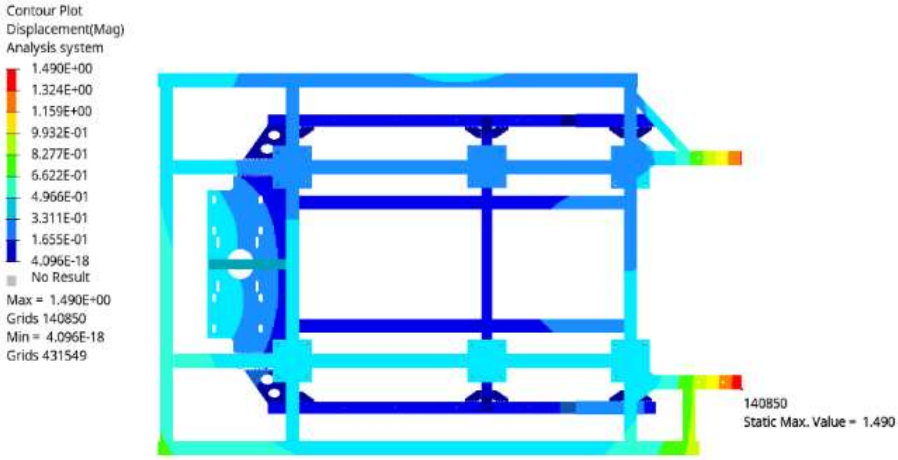


**Figure 8.** Frame displacement cloud diagram of half load transportation condition

From the above results, it can be seen that under the half-load full-load transportation condition, the maximum stress of the chassis frame is 206.1 MPa, which is less than the yield strength of the material. The maximum stress occurs at the longitudinal beam of the skidding assembly and the nearby strengthening area. The main reason is that the beam is equipped with a half-load skidding assembly. In the half-load skidding transportation, the transportation load acts on the longitudinal beam through the skidding assembly, and then acts on the main body of the frame, so that the local structure bears a large bending moment and shear force, so a relatively high stress level will be generated. It can be seen from the displacement cloud diagram that the maximum displacement under this working condition occurs at one end of the longitudinal beam of the skidding assembly away from the frame, mainly because the end is a cantilever support structure, which is less supported than other parts, and will bear the main transportation load in the half-load transportation, but the maximum deformation at this place is 1.49mm less than the allowable deformation of 5mm, and the chassis frame structure meets the use requirements.

# 5. Modal Analysis of Chassis Frame

## 5.1 Theoretical Basis

Modal is the inherent characteristic of the structure, which is often used to study the dynamic performance of the structure[11]. The machine will be subjected to dynamic excitation from the road surface and the range extender during operation. When the excitation is equal to the fixed frequency of the frame, resonance will occur, which will adversely affect the safety of the chassis frame. Therefore, it is necessary to carry out modal analysis of the frame structure, obtain its natural frequency and vibration mode characteristics, and evaluate the dynamic performance of the frame.

According to D 'Alembert 's principle, the differential equation of chassis frame system motion is[12]:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{F(t)\} \tag{1}$$

In the free modal analysis of the chassis frame, the damping of the frame has little effect on its natural frequency and vibration mode, so the effect of damping can be ignored, and in the free modal analysis, the influence of external load can also be ignored. Therefore, the system differential equation of the chassis frame in the free state is :

$$[M]\{\ddot{x}\}+[K]\{x\}=0 \tag{2}$$

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In the process of free vibration of the system, each node performs simple harmonic motion, and its displacement is expressed as follows:

$$\{x\}=\{x_0\}\sin(\omega t) \tag{3}$$

Where $\{x_0\}$ is the amplitude vector of the node ; $\omega$ is the natural frequency of the structure. Substituting it into the differential equation of the system, further available:

$$([K]-\omega^2[M])\{x_0\}=0 \tag{4}$$

In free vibration, the amplitude of each node is not all zero, so it is possible to obtain:

$$\left\|[K]-\omega^2[M]\right\|=0 \tag{5}$$

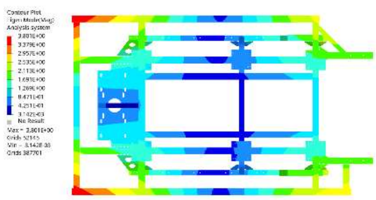
Based on the above analysis, it can be seen that for each first-order mode $\omega_i(i=1,2,3\cdots,n)$, in the structure, there is a corresponding eigenvector $\{x_0\}_i$, $\{x_0\}_i$ is the i-order vibration mode of the system.

## 5.2 Chassis Frame Modal Solution

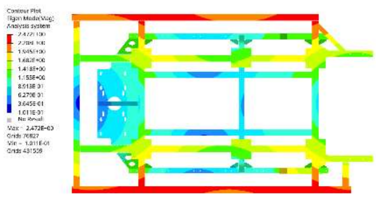
In the modal analysis of the structure, the amplitude of the high-order mode is very small and has little effect on the structure[13]. Therefore, this paper analyzes the first 12 order modal frequencies of the chassis frame. The free mode of the chassis frame is solved by the Lanczos method and solved by the OptiStruct solver. The analysis results show that the first six modes of the chassis frame are rigid modes, and the frequency is close to 0Hz. The influence on the structure can be neglected, so it is removed in the subsequent modal analysis[14]. The modal frequency obtained after removing the rigid body mode is shown in Table 2 below, and the corresponding vibration mode diagram is shown in Figure 9.

**Table 2.** Frame modal frequency

| Order | Modal Frequency（Hz) | Order | Modal Frequency（Hz) |
|---|---|---|---|
| **1** | 28.62 | **4** | 68.18 |
| **2** | 50.63 | **5** | 69.52 |
| **3** | 56.29 | **6** | 74.94 |



a) First-order modal shape



b) Second-order modal shape

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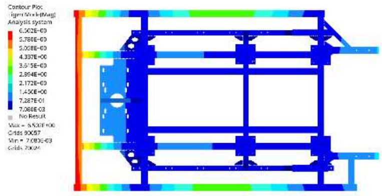
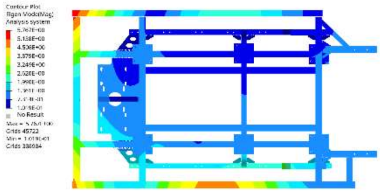
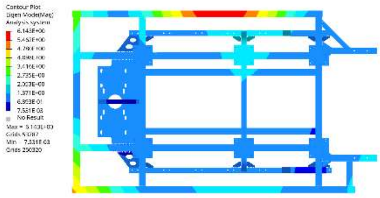


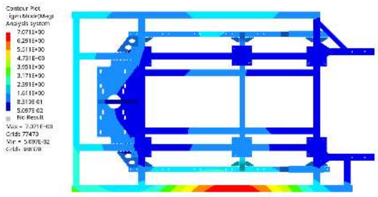
c) Third-order modal shape



d) Fourth-order modal shape



e) Fifth-order modal shape



f) Sixth-order modal shape

**Figure 9.** Frame modal vibration mode diagram

From the free modal analysis results of the chassis frame, it can be seen that the first 6-order non-zero modal frequencies of the frame structure are in the range of 28.62-74.94 Hz after removing the rigid body mode. The external excitation of the chassis frame is mainly road excitation and engine excitation. The vibration frequency generated by the road surface is usually a low-order vibration frequency less than 20 Hz[15]. Engine excitation refers to the power generated when the engine is working. The range extender of this power platform adopts a two-stroke two-cylinder horizontal opposed air-cooled gasoline engine. The frequency at idle speed is 25 Hz, and the engine frequency at normal operation is 86.67 Hz. There is no coincidence with the natural frequency of the chassis frame. Therefore, the excitation generated by the engine and the road surface will not resonate with the chassis frame.

## 6. Conclusion

(1) Based on the finite element simulation software, the overall stress distribution and deformation of the chassis frame under full-load and half-load transportation conditions are analyzed. Under full-load transportation conditions, the maximum stress of the chassis frame is 172.6 MPa, and the maximum deformation of the chassis frame is 1.18 mm. The maximum stress is 206.1 MPa and the maximum deformation is 1.49 mm under the condition of half-load transportation. It meets the physical properties of the selected material Q235 and can meet the safe use standard.

(2) The Lanczos method is used to solve the free mode of the chassis frame, and the first 12 free modes of the frame are extracted. After eliminating the rigid body mode, the modal frequency range

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of the chassis frame is 28.62 ~ 74.94 Hz. The results show that the natural frequency of the frame does not coincide with the excitation frequency of the road surface and the excitation frequency of the engine. The structure is not easy to resonate during the operation and has good dynamic performance.

(3) The comprehensive analysis shows that the designed chassis frame structure is reasonable and can meet the requirements under complex working conditions.

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