Based on the longitudinal and transverse seismic and shock absorption theory of tunnel structure, relying on the actual engineering, a finite element analysis model of a typical mountain tunnel was established. Four calculation conditions including the presence or absence of shock absorption layers and seismic joints are defined. The principal tensile (compressive) stress and displacement response of the vault, arch waist, foot of side wall, and middle of invert are studied. The results show that the shock absorption layer and the seismic joint have great influence on the dynamic response of the tunnel structure, which can reduce the main tensile (pressure) stress of different parts of the lining and change the way of stress distribution. The peak principal tensile (pressure) stress of the lining is reduced more obviously when the shock absorption layer and seismic joint are set. However, the presence of the shock absorption layer and the seismic joint will increase the peak displacement of each monitoring point of lining. The displacement of each monitoring point of lining is increased more obviously by the single shock absorption layer. Therefore, when the seismic design of the tunnel structure is carried out, the maximum seismic demand of the tunnel structure should be determined according to the specific calculation content in order to guide the design.

1. Introduction

In recent years, frequent earthquakes, especially strong earthquakes, not only are easy to cause landslides and collapses to block the tunnel portal, but also often lead to deformation of the tunnel lining, cracks of tunnel portal, and other earthquake damage [1–3]. Therefore, it is very important to study the dynamic response laws, seismic and shock absorption measures, and seismic safety evaluation of the tunnel structure in the high-intensity earthquake areas [4–6].

Based on the earthquake damage mechanism of underground structure, scholars at home and abroad put forward a new idea of reducing the earthquake damage of tunnel by setting shock absorption layer [7–9]. The effect of this method has been verified by theoretical analysis and model tests, which are mainly achieved by changing the performance of the tunnel structure itself or by setting a shock absorption device between the underground structure and the stratum [10–12]. Wang et al. [13] proved that the dynamic strain amplitude of the lining and the cracks of lining were reduced after the shock absorption layer was set by the analytical solution and the experiment. Xin et al. [14] proved that the shock absorption layer can improve the overall seismic capacity of the tunnel structure through the model test. Zhao et al. [15, 16] studied the effect of foam concrete as the shock absorption layer, compared the dynamic response of the seismic and isolated tunnel, and proved that the shock absorption layer has better effect on reducing earthquake force.

In summary, there are many research results on the shock absorption layer and seismic joint separately for the mountain tunnel structure. However, the study of considering seismic joint and shock absorption layer at the same time is relatively less. Based on this, this paper relies on an actual project to analyze the dynamic response laws and seismic performance of mountain tunnel structure under...
strong earthquake. The research in this paper is expected to provide the relevant theoretical basis for the seismic and shock absorption research of the tunnel structure and also provide a certain reference for similar projects.

2. Theoretical Study

2.1. Theoretical Analysis of Longitudinal Shock Absorption Theory. For the tunnel structure, the lining structure is constrained by the stratum, and its simplified mechanical model is shown in Figure 1. The dynamic equation can be expressed as

\[ EI y'' + K_0 y + \rho A \ddot{y} = K_0 u. \] (1)

It has been shown that the inertia force does not work in (1). Therefore, (1) can be simplified as

\[ EI y'' + K_0 y = K_0 u. \] (2)

The curvature radius of the lining structure can be deduced as

\[ \frac{1}{\rho} = \frac{-A(2\pi/l_0)^2 \cos^3 \phi \sin(2\pi x/(l_0 / \cos \phi))}{1 + (E/K_0)(2\pi/l_0)^4 \cos^4 \phi}. \] (3)

Therefore, the bending moment of the lining structure can be expressed as

\[ M = -EI \frac{1}{\rho} \frac{A(2\pi/l_0)^2 \cos^3 \phi \sin(2\pi x/(l_0 / \cos \phi))}{1 + (E/K_0)(2\pi/l_0)^4 \cos^4 \phi}. \] (4)

As can be seen from (4), \( M \) increases with the increase of \( E \) and \( K_0 \). When \( K_0 \) becomes large, \( E/K_0 \) tends to zero, and (5) can be derived as follows:

\[ \frac{1}{\rho} = -A \left( \frac{2\pi}{l_0} \right)^2 \cos^3 \phi \sin \left( \frac{2\pi x}{l_0 / \cos \phi} \right). \] (5)

Substituting equation (4) into equation (3),

\[ \frac{1}{\rho} = \frac{1}{M} = \frac{EIA \left( \frac{2\pi}{l_0} \right)^2 \cos^3 \phi \sin \left( \frac{2\pi x}{l_0 / \cos \phi} \right)}{1 + (E/K_0)(2\pi/l_0)^4 \cos^4 \phi}. \] (6)

Therefore,

\[ \frac{1}{\rho} = \frac{1}{M} = \frac{1}{1 + (E/K_0)(2\pi/l_0)^4 \cos^4 \phi} \leq 1. \] (7)

When the incident angle of local seismic wave is perpendicular to the tunnel axis (\( \phi = 90^\circ \)), the ratio of \( M/\rho \) is 1. Therefore, it can be seen from (6), under the condition of constant lining stiffness, that the softer the surrounding rock is, the smaller the internal force of the structure is. The internal force of the structure which ignores the inertial action is completely determined by the material and deformation characteristics of the structure. If the material stiffness of the structure is constant, the larger the deformation of the structure is, the greater the internal force is. The damage of this kind of structure is often caused by the excessive displacement given by the outside. If the stiffness of the surrounding rock is relatively large, the internal force of lining is completely determined by the forced displacement of surrounding rock. If the stiffness of the surrounding rock is very small compared to the lining, then the structure reduces its deformation due to its strong stiffness, which naturally reduces its internal force. Equation (6) is derived in consideration of this characteristic.

2.2. Research on Transverse Shock Absorption Theory. The dynamic performance of the lining structure can be improved by applying a shock absorption layer between the lining and the surrounding rock. When the earthquake occurs, the shock absorption layer has the ability to absorb the seismic energy and reduce the seismic response of the lining. The lining, damping layer, and surrounding rock are discretized by finite element method. According to their interaction, it is assumed that the shock absorption layer is the spring and damping connecting the lining and surrounding rock. One end of the spring is connected with the lining and the other end is connected with the surrounding rock, as shown in Figure 2. The simplified mechanical calculation model is shown in Figure 3, and the dynamic equation is shown in (8).

\[
\begin{bmatrix}
M & 0 \\
0 & M
\end{bmatrix}
\begin{Bmatrix}
\ddot{Y} \\
\ddot{Y}_1
\end{Bmatrix} + \begin{bmatrix}
C & -C \\
-C & C + C_1
\end{bmatrix}
\begin{Bmatrix}
\dot{Y} \\
\dot{Y}_1
\end{Bmatrix} + \begin{Bmatrix}
K & -K \\
-K & K + K_1
\end{Bmatrix}
\begin{Bmatrix}
Y \\
Y_1
\end{Bmatrix} = \begin{Bmatrix}
\dot{M} \\
\dot{M}_1
\end{Bmatrix} \dot{U},
\]

where \( U \) is the forced displacement caused by earthquake on the surrounding rock outside the shock absorption layer. \( Y, Y_1, M, M_1, C, C_1, K, \) and \( K_1 \) are the displacement, mass, damping, and stiffness on the lining and shock absorption layer.

Definition:

\[ U = U_0 \sin \omega_t \tau (n = 1, 2, 3, \ldots), \]

\[ Y = A \sin (\omega_t \tau + \varphi_A) = A_1 \sin \omega_t \tau + A_2 \cos \omega_t \tau, \]

\[ Y_1 = B \sin (\omega_t \tau + \varphi_A) = B_1 \sin \omega_t \tau + B_2 \cos \omega_t \tau, \]

where \( \omega_0 \) and \( \varphi_A \) are the circular frequency and the amplitude, and \( A \) and \( B \) are the displacement amplitude of the lining and shock absorption layer, respectively.

Substituting \( U, Y, \) and \( Y_1 \) into (8), the following equation can be obtained:
Through mathematical derivation, $A_1, A_2, B_1,$ and $B_2$ are sorted out. Let $A^2 = A_1^2 + A_2^2$, $B^2 = B_1^2 + B_2^2$. The ratio of the relative displacement of the lining and the shock absorption layer to the absolute displacement amplitude is expressed as

$$\eta = \frac{|A - B|}{U_0} = \frac{Z_1}{Z_2}$$

where $A$, $B$, and $U_0$ are expressed as follows.

$$A = \beta^4 \left[ 4(1 + f_m + f_k f_\beta f_\xi) \xi^2 + f_m (f_m^2 \beta^2 - 2 f_\beta^2 f_k^2 - 2 f_k - 2) \right]$$

$$B = \beta^2 \left[ 4(1 + f_m)^2 \xi^2 \beta^2 + \beta^2 (1 + f_m - f_m \beta^2)^2 \right]$$

Through mathematical derivation, $A_1, A_2, B_1, and B_2$ are sorted out. Let $A^2 = A_1^2 + A_2^2, B^2 = B_1^2 + B_2^2$. The ratio of the relative displacement of the lining and the shock absorption layer to the absolute displacement amplitude is expressed as

$$\eta = \frac{|A - B|}{U_0} = \frac{Z_1}{Z_2}$$

where $A, B,$ and $U_0$ are expressed as follows.

$$A = \beta^4 \left[ 4(1 + f_m + f_k f_\beta f_\xi) \xi^2 + f_m (f_m^2 \beta^2 - 2 f_\beta^2 f_k^2 - 2 f_k - 2) \right]$$

$$B = \beta^2 \left[ 4(1 + f_m)^2 \xi^2 \beta^2 + \beta^2 (1 + f_m - f_m \beta^2)^2 \right]$$

$$U_0 = \beta^2 + (\beta^2 - 1) \left[ (\beta^2 - 1) f_m (\beta^2 f_m - 2 f_k) + \left(1 - \frac{1}{\beta^2}\right) f_k^2 + 2 (f_k - f_m \beta^2) \right] + 4 \xi^2 \left[ \beta^2 (1 + f_k f_\beta f_\xi)^2 + (f_m \beta^2 - f_k) [2 + 2 f_m] \beta^2 - f_k + (4 \beta^2 \xi^2 - 2 \beta^2 + 1) f_\beta^2 f_k f_\xi \right].$$
of lining-shock absorption layer-surrounding rock system will decrease. Therefore, it is facilitating for system damping to reduce the stiffness and quality of the shock absorption layer. The United States has produced foam concrete with a density of less than 700 kg/m³, which is undoubtedly superior to reinforced concrete with a density of 2,500 kg/m³. The damping ratio is more sensitive than the mass ratio and stiffness ratio, and the damping layer structure with high damping ratio may be the focus of future research in the field of shock absorption in tunnel structure.

3. Engineering Description

The project is located in the road project from Bomê County to Mêdog County in Tibet. The tunnel site is characterized by the coexistence of high stress and high intensity earthquake, strong tectonic movement, and relatively developed fault structure. The lithology at the entrance of the tunnel is mainly gneissic granite, quartz schist, sericite schist, etc. The bedrock of the tunnel body and exit section is mainly granite, migmatite, etc. Some sections of the tunnel are mixed with a small amount of schist, gneiss, etc. The rock mass fissures and joints are developed.

Due to multiple sets of joints and fissure cutting, some rock masses are in the form of dangerous rock, and the rock is hard. The total length of the tunnel is 3330 m, the clear width of the carriageway is 7.00 m, and the basic seismic intensity of the site is 8 degrees. The tunnel section is shown in Figure 4.

4. Finite Element Model

4.1. Model and Boundary Conditions. According to the geological conditions and the design data of the tunnel, 101.8 m distance from the tunnel entrance is selected as the calculation range in this paper, and the maximum buried depth of the tunnel within this range is 47.5 m. The finite element model of the tunnel is established by using the general finite element software ANSYS. The finite element model is shown in Figure 5. The height and width of the finite element model are 85 m and 75 m, respectively. There are 37778 units in the finite element model, including 8352 lining units, 8447 shock absorption layer units, and 7487 seismic joint units. The calculation is divided into four conditions; each calculation model is shown in Table 1. When there is no damping layer, the element attribute of shock absorption layer is changed to surrounding rock, and when there is no seismic joint, the element attribute of seismic joint is changed to lining. The physical and mechanical parameters of the blocks of stone, surrounding rock, lining, reinforcement zone, shock absorption layer, and seismic joint are shown in Table 2.

In order to facilitate the extraction and analysis of the results, the lining unit is numbered, and the lining near the portal section is called no.① lining unit. With the increase of mileage stake number, the lining section number also increases in turn, and the lining number is shown in Figure 6. The shock absorption layer unit and the seismic joint unit are shown in Figures 7 and 8. In the calculation process, considering the infinite nature of the surrounding rock medium, preventing the reflection of seismic waves on the boundary, and allowing the boundary to have the ability to recover elastically, the bottom and side boundaries of the model are
set to viscoelastic artificial boundaries, and the ground surface is a free boundary. The boundary elements are shown in Figure 9.

### 4.2. Selection of Seismic Waves and Determination of Damping

When using the time history method to analyze the seismic response of the tunnel structure, it is necessary to

#### Table 2: Parameters of material physical mechanics.

| Material type         | $E$ (Pa) | $\mu$ | $C$ (Pa) | $\Phi$ (deg) | $\rho$ (kg/m$^3$) |
|-----------------------|----------|-------|----------|--------------|-----------------|
| Block stone           | 1.00e09  | 0.4   | 3.00e04  | 40           | 1500            |
| Surrounding rock      | 1.20e09  | 0.38  | 1.00e05  | 42           | 1800            |
| Reinforcement zone    | 2.40e09  | 0.34  | 2.00e05  | 42           | 2000            |
| Lining                | 3.35e10  | 0.2   | —        | —            | 2300            |
| Shock absorption layer| 3.50e06  | 0.38  | 0.60e03  | 6            | 1000            |
| Seismic joint         | 1.00e06  | 0.38  | 0.40e03  | 10           | 900             |

Figure 6: Numbering of lining.

(a) ![3D model of lining](image1.png)

(b) ![Local view of lining](image2.png)

Figure 7: Shock absorption layer element. (a) Entirety shock absorption layer grid. (b) Local shock absorption layer grid.

(a) ![3D model of seismic joint](image3.png)

(b) ![Side view of seismic joint](image4.png)

Figure 8: Seismic joint element. (a) Entirety seismic joint grid. (b) Right view of seismic joint grid.
directly input the seismic wave acceleration time history curves. However, the seismic wave is a nonstationary random process with a wide frequency band, which is affected by many factors and often gets different strong earthquake records at the same site for the same earthquake. In addition, the time history analysis shows that the seismic response is very different due to the different seismic wave input to the structure. Therefore, due to the randomness of the future ground motion and the difference of the calculation results in different seismic waves, the key factor to ensure the reliability of the calculation results is to reasonably select the seismic waves for direct dynamic analysis. According to the “Seismic Safety Evaluation Report” of this project, the peak acceleration of the base rock of the project site with a 50-year overrun probability of 10% proposed in the earthquake safety report is 3.21 m/s² as the peak acceleration. The seismic waves used in the calculation should be as close as possible to the seismic wave spectrum characteristics proposed in the “Seismic Safety Evaluation Report.” After screening, the Topanga Canyon seismic wave was selected (January 17, 1994, Northridge Earthquake, California, USA; collection location: Topanga Canyon, duration: 55.6 s, time interval: 0.02 s) as calculating seismic waves. In order to save the calculation time and avoid occupying a large amount of hard disk capacity during calculation, on the basis of keeping the Topanga Canyon wave spectrum characteristics unchanged, the FlexPro filter is used to low-pass filter it and intercept the first 5.56 s including its maximum peak as input seismic waves. The acceleration time history curves of X, Y, and Z are shown in Figure 10.

There are many factors affecting the damping in the dynamic problem. Generally speaking, Rayleigh damping is used in engineering. Rayleigh damping can be calculated by the following equation:

\[
[C] = \alpha [M] + \beta [K],
\]

where \( \alpha \) and \( \beta \) are called the damping coefficients, and they could be calculated by the following equations:

\[
\xi = \sqrt{\alpha \beta},
\]

\[
\omega = \sqrt{\frac{\alpha}{\beta}},
\]

\[
f = \frac{\omega}{2\pi},
\]

where \( \xi \) is the damping ratio, taking 5%. \( f \) is the natural vibration frequency. It can be seen from the finite element calculation that the natural frequency of calculation model A is 2.6752 Hz, the natural frequency of calculation model B is 2.4652 Hz, the natural frequency of calculation model C is 2.541 Hz, and the natural frequency of calculation model D is 2.3618 Hz. \( \omega \) is the circular frequency, which is solved by (18). \( \alpha \) and \( \beta \) can be obtained by combining (16)–(18).

5. Result Analysis

In order to compare and analyze the response laws of the peak principal tensile (compressive) stress and peak displacement of the lining structure under various working conditions, the distances from the tunnel entrance to 2.5 m, 5 m, 7.5 m, 12.65 m, 15.1 m, 17.55 m, 25.1 m, 35.1 m, 45.1 m, 55.1 m, 65.1 m, and 75.1 m were taken, and the peak principal tensile (compressive) stress and peak value of each section of the vault, arch waist, foot of side wall, and middle of invert were extracted during the vibration process. The corresponding conclusions are drawn by

![Figure 9: Viscoelastic boundary element. (a) Entire viscoelastic element grid. (b) Local viscoelastic element grid.](image-url)
Figure 10: Variation of acceleration. (a) Time history curve of seismic acceleration in transverse direction of the tunnel (X direction). (b) Time history curve of seismic acceleration in longitudinal direction of the tunnel (Z direction). (c) Time history curve of seismic acceleration in vertical direction of the tunnel (Y direction).

Figure 11: Peak principal tensile stress of the lining. (a) Vault. (b) Arch waist. (c) Foot of side wall. (d) Middle of invert.
tracking the peak principal stress and peak displacement variation law.

5.1. Principal Tensile (Compressive) Stress of Lining. The peak main tensile (compressive) stress of the vault, arch waist, foot of side wall, and middle of invert for lining about four calculation models at different locations from the tunnel entrance is shown in Figures 11 and 12.

It can be seen from Figures 11 and 12 that the shock absorption layer and the seismic joint can exert a very good shock absorption effect, greatly improving the safety of the structure. The use of shock absorption measures can significantly reduce the maximum internal force of the vault, arch waist, foot of side wall, and middle of invert on the same cross section and make the internal force on the same cross section more uniform. The stress concentration phenomenon is easy to occur at the foot of the wall, which is the weak part of the tunnel structure. The setting of the shock absorption layer has a particularly significant effect on the foot of side wall. Therefore, the shock absorption layer can effectively prevent the damage of the side wall.

In the earthquake damage investigation, it is found that the portal section of tunnel structure is seriously damaged, so it is necessary to analyze the dynamic response characteristics of the tunnel entrance under different seismic measures. Through the analysis of the calculation results of the tunnel portal section, it can be seen that with the increase of the distance between the monitoring section and the tunnel entrance, the main tensile (compressive) stress on the vault, arch waist, foot of side wall, and middle of invert decreases under the condition of no shock absorption layer and no seismic joint. After 15.1 m away from the tunnel entrance, the change of the principal tensile (compressive) stress tends to be stable. It can be considered that the relatively weak part of the tunnel portal section starts from the tunnel entrance and extends 15 m to the tunnel body. This distance value can be considered as an important reference.
index to determine the seismic fortification length of the portal section.

Figures 13 and 14 show the contribution of the two shock absorption measures to the reduction of the principal tensile (compressive) stress of the vault, arch waist, foot of side wall, and middle of invert when they are used alone or in combination. In this paper, the contribution rate ($c$) of shock absorption measures is defined as

$$c = 1 - \frac{\sigma_i - \sigma_0}{\sigma_0} \times 100\%,$$  \hspace{1cm} (19)

where $\sigma_i$ is the maximum main tensile (pressure) stress of the lining monitoring point under the $i$th model, and $\sigma_0$ is the maximum main tensile (pressure) stress of the lining monitoring point when there is no shock absorption layer and no seismic joint (Model A).

It can be seen from the analysis of Figures 13 and 14 that a single shock absorption layer, a single seismic joint, or both can effectively reduce the peak principal tensile (compressive) stress on the vault, arch waist, foot of side wall, and middle of invert. When the seismic joints are set at the same time, the reduction of the peak principal tensile (compressive) stress on the lining is more obvious. With the increase of the distance from the tunnel entrance (that is, the increase of the buried depth), the shock absorption effect of the shock absorber layer is better than that of the seismic joint in the shallow depth. However, with the increase of the buried depth, the shock absorption effect of the seismic joint is more excellent. The contribution rate of the shock absorption layer to the principal tensile (compressive) stress of the lining is greater than that of the seismic joint when the buried depth is less than 15 m. The contribution rate of the seismic joint to the principal tensile (compressive) stress of the lining is greater than that of the shock absorption layer when the buried depth is greater than 23 m.

\[\text{Figure 13: The contribution rate} (c) \text{ of shock absorption measures to the reduction of the main tensile stress for lining. (a) Vault. (b) Arch waist. (c) Foot of side wall. (d) Middle of invert.}\]
5.2. *Displacement Analysis*. The peak displacements in $X$, $Y$, and $Z$ directions for the vault, arch waist, foot of side wall, and middle of invert for different models are studied, as shown in Figures 15–17.

From the analysis of Figures 15–17, it can be seen that the peak displacements of the vault, arch waist, foot of side wall, and middle of invert on the same section almost coincide. The relative displacement difference of lining between monitoring points in $Z$ direction is slightly larger, and the maximum relative displacement difference is about 2.92 mm. The above conclusion shows that no matter there is a damping layer or a seismic joint, the rigid displacement of the lining structure basically occurs in the process of vibration, and the integrity is good.

Figures 18–20 show the variation laws of the peak displacement of each monitoring point, which is in $X$, $Y$, and $Z$ direction for the vault, arch waist, foot of side wall, and middle of invert of the four calculation models.

It can be seen from Figures 18–20 that the existence of the shock absorption layer and the seismic joint will increase the peak displacement of each monitoring point of the lining. When the shock absorption layer and seismic joint are set at the same time, the peak displacement of lining increases the most, the maximum value of transverse peak displacement reaches nearly 10 cm, the maximum value of vertical peak displacement reaches nearly 18 cm, and the maximum value of longitudinal peak displacement reaches nearly 12 cm.

Compared with a single seismic joint, a single shock absorption layer increases the displacement of each monitoring point of the lining more obviously. When the single shock absorption layer is installed, the maximum value of...
Figure 15: Peak displacement in $X$ direction along the longitudinal direction of the tunnel. (a) Model A. (b) Model B. (c) Model C. (d) Model D.

Figure 16: Continued.
Figure 16: Peak displacement in Y direction along the longitudinal direction of the tunnel. (a) Model A. (b) Model B. (c) Model C. (d) Model D.

Figure 17: Peak displacement in Z direction along the longitudinal direction of the tunnel. (a) Model A. (b) Model B. (c) Model C. (d) Model D.
Figure 18: The peak value of $X$ direction displacement of each measuring point changes along the longitudinal direction of the tunnel. (a) Vault. (b) Arch waist. (c) Foot of side wall. (d) Middle of invert.

Figure 19: Continued.
Figure 19: The peak value of $Y$ direction displacement of each measuring point changes along the longitudinal direction of the tunnel. (a) Vault. (b) Arch waist. (c) Foot of side wall. (d) Middle of invert.

Figure 20: The peak value of $Z$ direction displacement of each measuring point changes along the longitudinal direction of the tunnel. (a) Vault. (b) Arch waist. (c) Foot of side wall. (d) Middle of invert.
the transverse peak displacement of the lining can reach nearly 3.5 cm, the maximum value of the vertical peak displacement can reach nearly 1.95 cm, and the maximum value of the longitudinal peak displacement can reach nearly 6.84 cm. When the seismic joint is provided alone, the maximum value of the transverse peak displacement of the lining can reach nearly 2.3 cm, the maximum value of the vertical peak displacement can reach nearly 1.75 cm, and the maximum value of longitudinal peak displacement can reach nearly 0.4 cm.

6. Conclusion

In this paper, four calculation models are established for the mountain tunnel structure with or without shock absorption layer and seismic joints, and the seismic research is carried out to obtain the following conclusions:

(1) Whether it is a single shock absorption layer, a single seismic joint, or both, the maximum internal force on the same cross section can be greatly reduced in the vault, arch waist, foot of side wall, and middle of invert, and the internal force on the same cross section is more uniform. However, the fact that the distribution of the principal tensile (compressive) stress on the lining also changes cannot be ignored.

(2) With the increase of the distance from the monitoring point to the tunnel entrance, the principal tensile (compressive) stress on the vault, arch waist, foot of side wall, and middle of invert decreases first and then tends to be stable when there is no damping layer and seismic joint. Therefore, we can use the change of stress to judge the weak area of the tunnel portal section, and determine the fortification length of the tunnel portal section.

(3) When the shock absorption layer and seismic joint are set at the same time, the effect of reducing the peak principal tensile (compressive) stress on the lining is more obvious. With the increase of the distance from the monitoring point to the tunnel entrance, the shock absorption effect of the shock absorption layer is better than that of the seismic joint in the shallow buried depth. However, with the increase of buried depth, the seismic joint has more excellent damping effect. Therefore, the contribution rate of the shock absorption layer and the seismic joint to the reduction of the principal tensile (compressive) stress of the lining is related to the burial depth.

(4) On the same section, the difference of the peak displacement of the vault, arch waist, foot of side wall, and middle of invert is small. It is proved that no matter whether there are shock absorption layers or seismic joints, the rigid body displacement of the lining basically occurs in the process of vibration, and the integrity is good.

(5) The existence of the shock absorption layer and the seismic joint will increase the peak displacement of each monitoring point of the lining. When the shock absorption layer and the seismic joint are set at the same time, the peak displacement of the lining increases the most. Compared with the tunnel with seismic joints alone, the tunnel with shock absorption layers separately has a more obvious effect on increasing the displacement of each monitoring point of the lining.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors’ Contributions

Zhi Lin and Lei Yan contributed equally to this work.

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