Journal of Civil Engineering and Urban Planning (2025)
Clausius Scientific Press, Canada

DOI: 10.23977/jceup.2025.070104
ISSN 2616-3969 Vol. 7 Num. 1

Research on seismic reinforcement of traditional houses in Yunnan Province "Dai stilted buildings"

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Keywords: Dai stilted buildings; Viscoelastic damper; Nonlinear time history analysis; Sap2000; Torsion resistance

Abstract: In this paper, the following research work is carried out on the seismic reinforcement of the Dai minority bamboo buildings in Yunnan in the earthquake prone zone: (1) Research on the selection of seismic reinforcement measures. (2) In order to study the mechanical mechanism of seismic reinforcement of traditional residential buildings by dampers, the seismic reinforcement characteristics and adaptive conditions of viscoelastic dampers, buckling-resistant braces and friction dampers are studied. The results show that with the strengthening of seismic wave, compared with the ordinary structure, the building structure with dampers has more seismic performance. In terms of seismic characteristics, the three seismic strengthening methods all show certain seismic capacity. (3) In order to study the mechanical effect of the seismic strengthening form, the seismic test data of the simple building structure and the building structure with spring damper are used to evaluate its strength index. The results show that: (1) compared with ordinary structures, the spring damper can significantly improve the seismic capacity of the structure with the strengthening of seismic waves; (2) the spring damper converts the energy generated by seismic waves into elastic potential energy and consumes energy in the process of energy conversion, which maintains the integrity of the structure and improves the safety; The transformation of energy conforms to the law of conservation of energy.

1. Introduction

Yunnan Province is one of the regions with the most intense modern crustal movement and strong seismic activity in the world, due to the dual dynamic effects of the eastward subduction of the Indian plate along the Yunnan-Myanmar arc and the lateral extrusion of the Qinghai massif. The seismic activity in Yunnan is characterized by high frequency, high intensity, wide distribution and severe disasters. Yunnan Province is one of the regions with the most intense modern crustal movement and strong seismic activity in the world, due to the dual dynamic effects of the eastward subduction of the Indian plate along the Yunnan-Myanmar arc and the lateral extrusion of the Qinghai massif. The seismic activity in Yunnan is characterized by high frequency, high intensity, wide distribution and severe disasters.

The Dai are one of the ethnic minorities in China, mainly in Xishuangbanna Dai Autonomous Prefecture, Dehong Dai Jingpo Autonomous Prefecture and Gengma and Menglian Autonomous Counties in Yunnan Province. In the long-term life, the Dai people have formed their own house architectural features-stilted buildings (fig.1). The Dai stilted building is made of bamboo, wood and thatch, which are abundant in the local area, and the structure of piercing bucket and mortise and tenon is completely used, which makes the building have a certain degree of flexibility, but the overall stability is not strong.

Figure 1: Dai stilted house

Figure 2: Dai stilted house destroyed by the earthquake

In recent years, due to the shortage of bamboo and wood, the price is expensive, the production process is complex and other reasons, the local villagers mostly use brick pillars to replace the bamboo and wood load-bearing self-built stilted buildings, the strength of the masonry mortar is very low, the seismic performance of the structure is very poor, and once an earthquake occurs, it will cause serious casualties (fig.2).

The traditional Dai stilted low-rise buildings, and the existing seismic design is mostly suitable for high-rise buildings, and the traditional houses often lack seismic design, which is seriously damaged in small and medium-sized earthquakes, and greatly damages the safety of people's lives and property. We hope to use the existing technology to find a solution to the seismic safety problem of Dai people's houses[5].

Compared with the traditional seismic reinforcement method, the seismic reinforcement of the damper is more feasible and economical, on the other hand, the seismic reinforcement of the damper can ensure the originality of the house structure and better protect the cultural landscape.

At present, the seismic absorption methods of wood structures in various countries in the world are mainly as follows: one is to isolate the impact caused by earthquake on the structure by installing rubber elastic pads or friction bearing seats and other equipment at the bottom of wood structure buildings; the other is to reduce and isolate vibration by connecting the structural wooden column with the foundation; In addition, the bucket arch can also be set on the timber structure, which can strengthen the strength of the core area of the node and improve the seismic performance. The installation of dampers on the timber structure is also a good way to resist vibration and damping vibration, and now large reinforced concrete structures and high-rise buildings are used to use a variety of dampers for seismic reinforcement, which indirectly provides a feasibility demonstration for the damper to strengthen small wooden structures.

2. Types and characteristics of seismic dampers

The seismic reinforcement technology of damper is to use the damper to set up dampers in some parts of the building structure, such as between columns, nodes, joints, floor spaces, etc., to increase the damping of the structure, consume the vibration energy of the structure under the earthquake, reduce the vibration response of the structure, and achieve the purpose of structural seismic resistance; Achieve relative stability and integrity of the building structure under seismic conditions.

The safety of the house structure is the premise for the existence and reinforcement of the house, and it is also the fundamental guarantee for the lives and property of residents and tourists. The seismic reinforcement of the damper should meet the requirements of the structural function and stability of the house, and then reduce the cost of the project in combination with the local mountainous terrain and unfavorable traffic conditions in Yunnan.

The seismic reinforcement of dampers should be selected mainly in combination with the successful cases of seismic reinforcement of local building dampers in Yunnan, and at the same time, combined with the local environment, the selected dampers are required to be easy to purchase, easy to install, good seismic reinforcement performance, and low economic cost.

Viscoelastic dampers are composed of viscoelastic materials and constraining steel plates, and common viscoelastic dampers include flat viscoelastic dampers and cylindrical shear viscoelastic dampers. It is composed of two T-shaped restraint steel plates and a rectangular steel plate, and a layer of viscoelastic material is sandwiched between the contact surface of the T-shaped restraint steel plate and the intermediate steel plate, and the steel plate and the viscoelastic material are made into a whole by vulcanization method. Under the action of repeated axial force, the relative motion of the T-shaped confined steel plate and the central steel plate causes the reciprocating shear deformation of the viscoelastic material, thereby dissipating the motion energy in an endothermic manner. Cylindrical shear viscoelastic damper: It is composed of a layer of viscoelastic material between two steel cylinders, and the steel cylinder and viscoelastic material are made into a whole by vulcanization. Its energy dissipation mechanism is the same as that of flat plate viscoelastic dampers [6].

A buckling restrained brace is a support that places a peripheral restraint sleeve around the steel core, which can yield under both tension and compression, thereby suppressing buckling. The center of the support is the core material. To prevent overall buckling of the core material under compression, and to ensure it can yield under both tension and compression, the core material is placed inside a steel pipe sleeve, and concrete or mortar is then poured into the sleeve. To reduce or eliminate the forces transmitted to the mortar or concrete when the core material is subjected to axial force, and due to the Poisson effect, which causes the core material to expand under compression, a layer of unbonded material or a very thin layer of air is placed between the core and the mortar.

Advantages: (1) Compared with bending rigid frames, it provides greater linear elastic stiffness during small earthquakes, making it easy for the frame to meet the deformation requirements of the standards. (2) It has stronger and more stable energy dissipation capacity during large earthquakes or extreme intensity earthquakes. (3) The supporting members act like replaceable fuses in the structural system, protecting other components from damage and allowing for easy replacement of damaged supports after a large earthquake. (4) The frame support structure has strong anti-collapse capability, and buckling-restrained braces are superior to traditional support systems in seismic reinforcement. Disadvantages: (1) High cost. (2) Large equipment is not conducive to installation and transportation. (3) It affects the aesthetics and characteristics of traditional houses.

Friction dampers slip or deform under predetermined loads before the main structural components yield, relying on friction or damping to dissipate seismic energy. At the same time, due to the lengthening of the natural vibration period after the deformation of the structure, the seismic input is reduced, so as to reduce the seismic response of the structure.

The selection of dampers should adhere to the following principles, which are beneficial for the seismic stability, safety, economic feasibility, and implementability of the housing structure. After assessing the costs, installation and transportation difficulties, and seismic performance of various dampers, we ultimately chose viscoelastic dampers as the seismic reinforcement equipment for the stilted houses of the Dai ethnic group, a traditional dwelling in Yunnan. Most traditional Dai stilted houses in Yunnan are made of bamboo or wood, and viscoelastic dampers provide effective seismic reinforcement for wooden structures. Viscoelastic dampers are low-cost, easy to install and transport, and suitable for wooden structures, ensuring that the structure can withstand minor earthquakes without damage, be repaired after moderate earthquakes, and remain standing during major earthquakes.

3. Analysis of the time history of Dai stilted buildings under the action of ground motion

3.1 Earthquake disaster

The main damage of an earthquake to a house is mainly the damage to the structure of the house by seismic waves, which in turn destroys the stability of the overall structure of the house, resulting in the collapse and destruction of the house building. Seismic waves are elastic waves that radiate from the hypocenter in all directions. When an earthquake occurs, the medium in the epicenter area undergoes rapid rupture and movement, and this disturbance constitutes a wave source. Due to the continuity of the Earth's medium, this wave propagates to the interior of the Earth and to all parts of the surface, forming elastic waves in the continuum.

Seismic waves are the main factors causing damage to buildings. For wooden and bamboo structures, the primary part that is often damaged by seismic waves is the node structure of the building, which ensures the integrity of the nodes and thus protects the safety of the building structure. The viscoelastic damper can absorb the energy brought by the seismic waves when they arrive and release the absorbed energy during the duration of the seismic waves, thereby protecting the integrity and safety of the original structure.

3.2 Model selection

The traditional houses of the Dai ethnic group are mainly two-storey structures, with pillars and beams forming a super-static structure; Therefore, the Dai ganlan-style house building still exists after countless earthquakes, which is enough to show that the traditional wooden structure of bamboo houses has good earthquake resistance; Nowadays, the traditional dwellings are generally historical, and have experienced many large and small earthquake damages, resulting in some nodes of the structure have no effectiveness, and the installation of viscoelastic dampers at the nodes can make the invalid nodes re-stressed and then prolong the life of the Dai dry column house building, improve its safety, and achieve the purpose of protection and development.

The load on the building refers to the loads acting on the structure, which mainly include the self-weight of the first-floor frame, the self-weight of the second-floor composite wall, the self-weight of the wooden truss, the dead load of the floor, the live load on the floor, and the dead and live loads of the roof.

According to China's Code [1-4] for Loading of Building Structures GB55001-2021, it is obtained:

(1) The live load of the floor is 2.0 kN/m^2; (2) The live load of the roof is 0.5 kN/m^2(3) The self-weight of the one-story composite floor slab is 2.26kN/m^2;(4) The self-weight of the composite

(wood and bamboo) wall is: 2.50 kN/m;(5) The self-weight of the roof (including waterproofing membrane and purlin): 0.45 kN/ m^2;(6) The self-weight of each component: the self-weight of the main beam (120×120mm) is 0.185 kN/m; Secondary beams. The beam (100×100mm) has a dead weight of 0.143 kN/m; Wooden column (160×160 mm)The dead weight is 0.228 kN/m; From these data, the self-weight of the components can be obtained from the length and dimensions of the actual components in the structure.

3.3 Finite element software analysis

Dai house structure plus viscoelastic damper analysis: First, the overall structure of the house was established by SAP2000v23 software and simplified model. According to paragraph 5.1.2 of China's Code for Seismic Design of Buildings, Xishuangbanna belongs to an 8 degree (0.2g) area, and the peak acceleration is 400 gal when it is rare to encounter earthquake time history analysis, so the El centro wave (fig.3) is selected and the peak acceleration is adjusted to 400 gal.

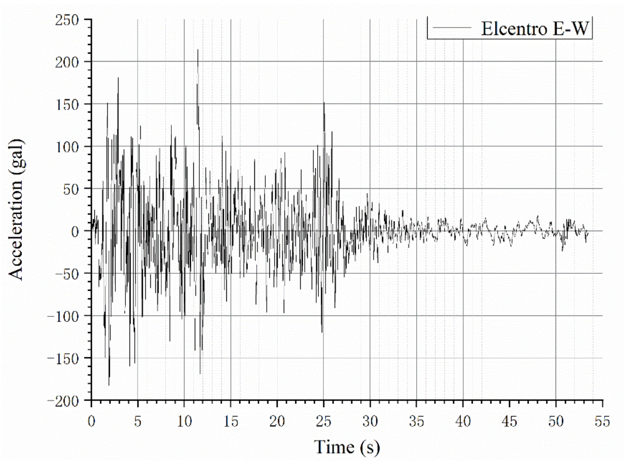

Figure 3: El centro seismic wave

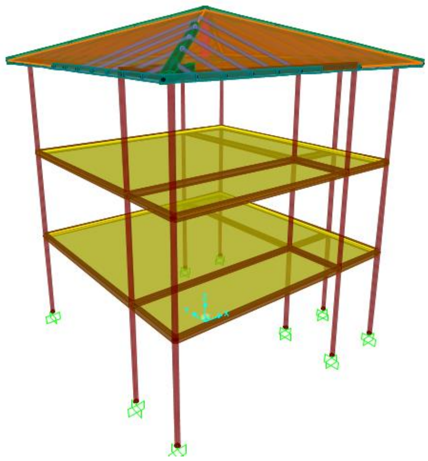

Figure 4: Renderings of the model

According to Ref. [7-10], the SFA model of a three-story Dai stilted building was established by using SAP2000.The modeling uses frame elements, the column bases use spatial hinge supports, and the models of each part are shown in Figure 4.

The results of the analysis of the time history of the shockless device are shown in Figures 5-8.

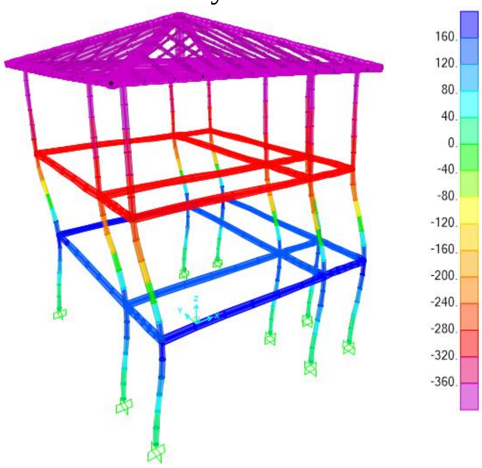

Figure 5: X-direction displacement contour (mm)

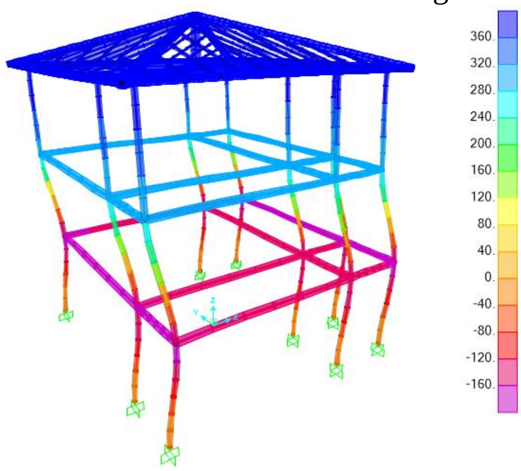

Figure 6: Y-direction displacement contour (mm)

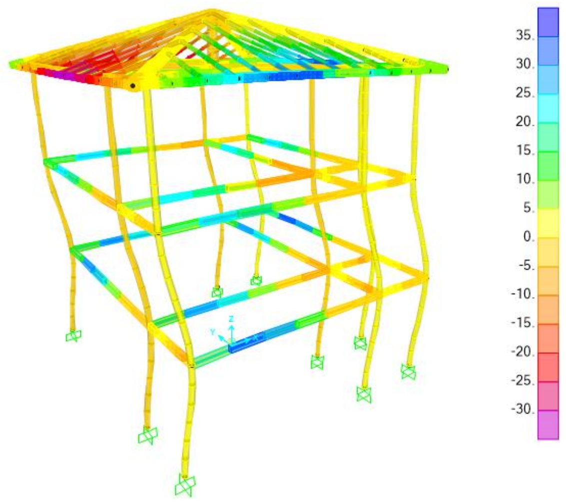

Figure 7: Z-direction displacement contour (mm)

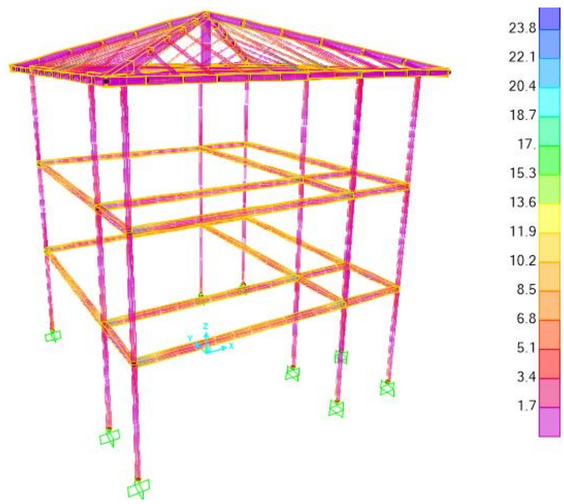

Figure 8: s11 Direction Stress Contour (MPa)

It can be seen from the Z-displacement contour diagram that the Z-displacement is not large, and it is less than 35mm. It can be seen from the X-direction displacement contour map that the roof displacement is as high as 360mm, and it is likely that it has fallen during the actual earthquake, but the roof is not a load-bearing structure, and its damage has a weak impact on human safety. The displacement of the first layer frame reaches 160mm, and the displacement of the second layer frame reaches 280mm; The three layers reach 360mm; It can be seen from the Y-direction displacement cloud map that the displacement of the roof is as high as 360mm, and it is likely that it has fallen during the actual earthquake, but the roof is not a load-bearing structure, and its damage has a weak impact on human safety. The displacement of the first layer frame reaches 160mm, the second layer of the frame reaches 280mm, and the third layer reaches 360mm, which is bound to threaten human safety. From the s11 stress contour diagram and stress filling diagram, it can be seen that the nearby stress of the first, second and third layers of beams connected to the column reaches about 19MPa. According to Section 4.2.1 of the Code for the Design of Timber Structures, the design value of the tensile strength of the timber along the grain is about 8MPa, and the design value of the compressive strength is about 10MPa.

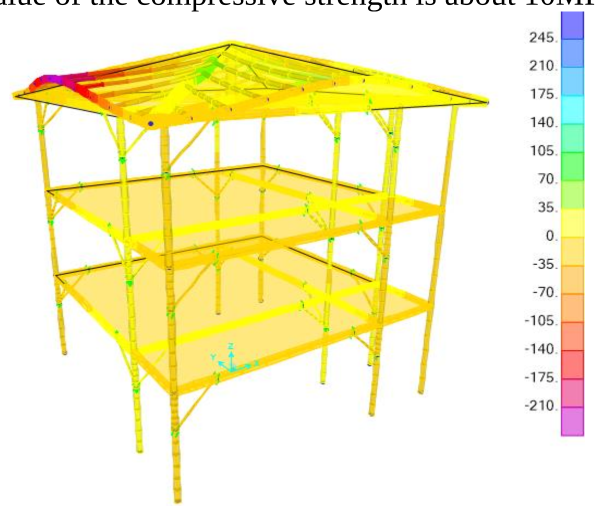

Figure 9:X-direction displacement contour (mm)

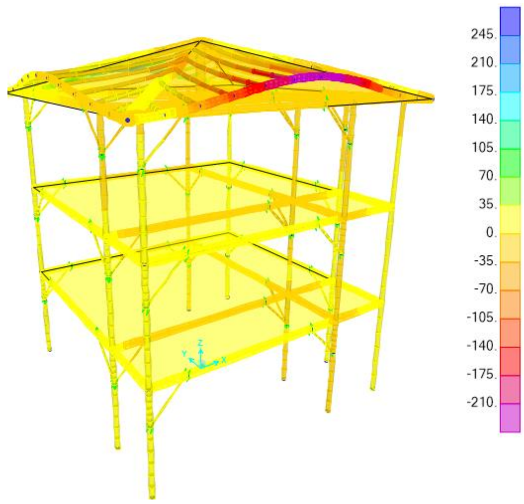

Figure 10: Y-direction displacement contour (mm)

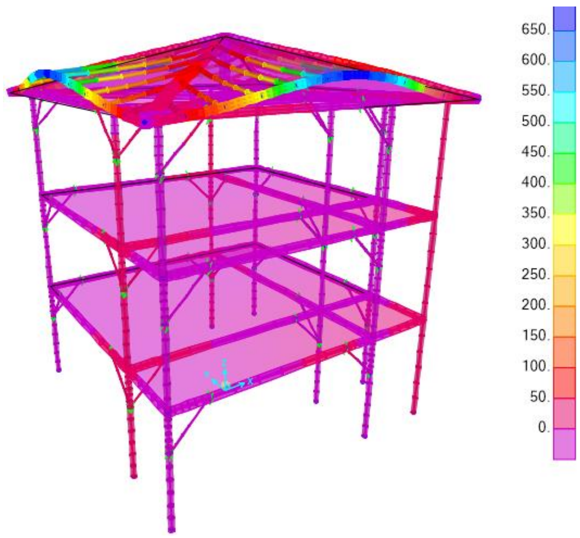

Figure 11: Z-direction displacement contour (mm)

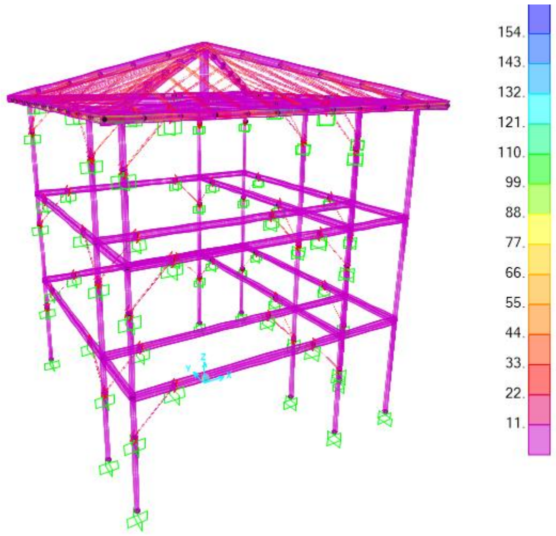

Figure 12: s11 Direction Stress Contour (MPa)

Time history analysis with damping devices: Based on the results of the above analysis, spring dampers were added near the beam-column connections with a large span. The working conditions remain unchanged, and the time history analysis is still conducted under the rare 8-degree earthquake scenario, with the results shown in Figures 9 to 12.

It can be seen from the Z-direction displacement contour diagram that the Z-direction displacement is not large, less than 50mm, except for the individual positions of the load-bearing part of the roof. It can be seen from the X-direction displacement contour diagram that the displacement of individual positions reaches 210mm except for the displacement of the roof, but the roof is not a load-bearing structure, and its damage has a weak impact on human safety. The displacement of the first, second and third layers of the frame is less than 35mm; It can be seen from the Y-direction displacement contour diagram that the displacement of individual positions reaches 210mm except for the displacement of the roof, but the roof is not a load-bearing structure, and its damage has a weak impact on human safety. The displacement of the first, second and third layers of the frame is less than 35mm.

From the stress contour and stress filling diagrams of s11, it can be seen that the stress near the connections of the first, second, and third layer beams with the columns has been transferred to the energy dissipation and damping device, and the maximum stress of the frame beam-column is about 5MPa. According to Section 4.2.1 of the Code for the Design of Timber Structures in China, the design value of the tensile strength of timber along the grain is about 8MPa, and the design value of the compressive strength is about 10MPa. Therefore, under the current seismic load, this structural component will not suffer serious damage.

4. Conclusions

On the basis of summarizing and analyzing the dry-column houses of the Dai ethnic minorities in Yunnan Province, this paper focuses on the advantages and disadvantages of several kinds of dampers, and then selects the viscoelastic dampers that can meet the seismic reinforcement of the houses according to their naturalness, integrity and economy in the face of the characteristic Dai traditional dwellings, analyzes the variation law of the resistance strength of tensile and compressive failure, shear failure and torsional failure of the building joints, and derives the relationship model between the damper and the seismic wave intensity, the tensile and compressive strength model, The shear strength model and torsional strength model, combined with specific examples to illustrate the influence of viscoelastic damper on the seismic reinforcement stability of the house, the following conclusions are obtained in the study:

The seismic reinforcement of the local cultural heritage Dai traditional dry-column house building - Dai bamboo building has strong implementation; According to the type of housing construction, economic rationality and operability, the seismic reinforcement method was selected, and the viscoelastic damper was selected for seismic reinforcement in combination with the actual types of seismic reinforcement in Yunnan Province.

By conducting a nonlinear time history analysis of the structure without an increased viscoelastic damper and the structure with an increased viscoelastic damper, seismic reinforcement test data under both conditions are obtained. By comparing these two sets of data, it can be concluded that the viscoelastic damper has a direct impact on the seismic reinforcement of buildings and ensures the integrity of the building structure.

Acknowledgements

The support of Frontier Research Team of Kunming University 2023 is gratefully acknowledged. The authors also acknowledge the financial support from the Yunnan Province Foreign Talent Introduction Special Project - Key Foreign Expert Project (Grant No. 202505AO120030). The authors also acknowledge the support of Kunming University Science and Technology Innovation Team 2020.

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