Exploration into the Anti-Seismic Technologies in the Museum

Jingneng Tian¹, Maomao Song²*, Mansheng Zhang² and Jiao Pan¹

¹Yunnan Provincial Museum, Kunming, China
²China Aviation Planning and Design Institute (Group) Co., Ltd., Beijing 100120, China
Email: 544166780@qq.com

Abstract. The overall seismic isolation structure is adopted for Yunnan Provincial Museum. The paper explores anti-seismic technologies for both museum buildings and collections, offers seismic protection analysis and design for precious museum collections by taking into account seismic waves, buildings, exhibition facilities and collections as a whole. Based on the demand for protecting museum collections from earthquakes, the paper discusses proper anti-seismic technologies for the museum structure, exhibition facilities, showcases and collections; it offers the dynamic time-history analysis of seismic isolation structure in rare earthquakes, and gives anti-seismic analysis and design for collections based on the acceleration response of the floor on different levels. Conclusions: The seismic protection for museum collections shall take into consideration seismic transmission from the venue and structure to exhibition facilities, showcases and collections. Under seismic actions, the acceleration response of the floor of exhibition halls on different levels of the museum varies greatly, the seismic response of showcases reinforced with anti-seismic measures decreases significantly, which ensures the safety of museum collections in earthquakes. The paper focuses on the anti-seismic technical route, technical measures, assessment results and implementation suggestions, offering reference for the construction of new museums and the seismic preventive conservation of collections.

1. Introduction
Yunnan Province lies on the seismic belt of frequent strong earthquakes, with felt earthquakes happening dozens of times or even over 100 times annually on average. Earthquakes are sudden and highly destructive natural disasters. Since we can’t accurately forecast or control earthquakes technically so far, it’s of great significance to protect museums and collections from earthquakes by engineering and technical means. The Wenchuan Earthquake that took place on May 12, 2008 and the Lushan Earthquake that happened on April 20, 2013 both caused damage to many precious museum collections [1-2]. The earthquake damage to museum collections shows seismic motion is transmitted from museum building structures to showcases and collection mounts. Damage to any part of them will endanger the collections. To better protect building structures and museum collections from earthquakes, some newly built museums at home have improved anti-seismic standards or adopted advanced shock mitigation and isolation systems, which can significantly ease the earthquake response from building structures, but can’t ensure the safety of collections, either. For example, despite the improved anti-seismic structural design of a certain museum built after the 5.12 Wenchuan Earthquake, many precious collections were still damaged in the 4.20 Lushan Earthquake that happened five years later, although the museum building and people were basically safe [2].

Wu Laiming et al. of Shanghai Museum [3] took the lead and put forward the design concept that
takes into account the response spectrum of different floors of a museum building; Ge Jiaqi [4] proposed the design philosophy that addresses the seismic problem by thinking about seismic wave, buildings, exhibition facilities, showcases and collections as a whole, which laid a foundation for the all-round implementation of the preventive conservation of museum collections at home; Ma Botao et al. [5] conducted theoretical research on relevant design methods based on the said systematic design philosophy; Yang Weiguo [6] and Yao Lijie [7] et al. adopted finite element simulation to analyze museum structures and conduct simulation study on museum collections; Pomei A, Scalia A [8] et al. used rigid blocks to represent collections, studied their motions under horizontal earthquakes, and determined the standards for the rigid blocks to slide or rotate. Meanwhile, in countries like the US and Japan, much research has been done on mechanical earthquake isolation devices, and horizontal and vertical earthquake isolation devices have been applied to museums, which greatly improves the safety of museum collections [9].

The paper explores the anti-seismic technologies adopted for Yunnan Provincial Museum from buildings to collections, and offers demonstration research on the seismic protection technologies for precious museum collections by thinking about seismic wave, buildings, exhibition facilities (showcases) and collections as a whole.

2. Anti-Seismic Technical Strategy

Museums are not only public buildings where large-scale activities are held, but also safe spaces for the collection and exhibition of material treasures. Systematic design based on the safety of people and collections is a focus of museum design.

2.1. The Anti-seismic Technical Strategy for Museum Buildings

2.1.1. Site Selection. The selection of a museum site shall be aligned with the master plan for urban construction, and help the museum give the biggest play to its social functions. In China, many provinces are situated in dangerous seismic belts, and thus are areas with potential secondary geological disasters of earthquake, such as Sichuan, Yunnan, Gansu, Shanxi, Shaanxi and Tibet. Such areas see a big number of museums of all types, but we find it’s hard to effectively and economically resist the secondary geological disasters triggered by earthquakes with the technical means available so far. An effective way is to do a good job in site exploration and selection before construction and build the museum in a belt with relatively stable and safe geological conditions. Yunnan Provincial Museum is affected by Xiaojiang Fault and Pudu River Fault. Although the site selection avoids the main seismic belt as much as possible, the museum is still located in unfavorable seismic belt, with the basic condition as Earthquake Group III and Site Category III.

2.1.2. Anti-seismic Technologies. Seismic protection in building structures is technically enabled through seismic resistance, seismic mitigation and seismic isolation. Globally, Japan and China take the lead in the technical research and engineering practice in seismic mitigation and isolation. Through the engineering practice in recent years, China has seen the following technical damping categories developed, as shown in figure 1.

![Figure 1. The overview of anti-seismic technologies.](image)
(1) Seismic Mitigation Technologies.

Seismic mitigation technologies are intended to mitigate the response of building structures to earthquakes. Energy absorption and seismic mitigation devices [10] include active control devices, passive control devices and semi-active control devices. Active control devices curb the seismic motion response of building structures through electricity-driven energy absorbers; without the input of external energy, passive control devices convert the structural kinetic energy triggered by earthquakes into internal energy through numerous energy absorbing components arranged in buildings. Based on working principles, passive control devices further break down into metal dampers, viscoelastic dampers, friction dampers and viscous dampers, etc.

(2) Seismic Isolation Technologies.

Seismic isolation technologies refer to the arrangement of seismic isolation layers at the bottom of buildings or between floors to isolate or reduce seismic energy transmitted to building structures, as shown in figure 2. When seismic action comes, the structure above the seismic isolation layer can move horizontally as a whole to ease earthquake energy. Main seismic isolation technologies applied at present include seismic isolation through rubber supports, seismic isolation through friction pendulums, and seismic isolation through sliding supports. Seismic isolation technologies are highly effective in reducing seismic input, and are increasingly used in key projects.

![Figure 2. The diagram of the seismic isolation structure.](image)

2.2. Anti-Seismic Technical Strategy for Exhibition Facilities

2.2.1. Anti-seismic Measures for Exhibition Facilities. Exhibition maintenance facilities are not the main stress components of building structures. Such non-main structural components typically lack mechanical design or anti-seismic measures, but depend on experience in installation. After an earthquake, even if the main beams, columns and walls of a museum building don’t crack or collapse, the suspended ceilings, wall decorations or some other supports and hanging brackets running inside suspended ceiling will break and drop, smashing collection showcases and causing damage to museum collections.

Proper reinforcing measures shall be adopted for the suspended ceilings, wall decorations and decorative components that may cause damage to museum collections after breaking and falling down under seismic action.

2.2.2. Anti-Seismic Measures for Showcases and Exhibition Appliances.

(1) Large Showcases

Generally, there are two main anti-seismic solutions for independent large showcases or showcases along the wall: i) the anti-seismic solution adopted for the exhibit stands in showcases, to enable seismic isolation between collections and exhibit stands, and ii) the anti-seismic solution applied to the bottom of showcases (figure 3). When seismic action transmits to anti-seismic devices, the boards on and under the devices move relatively, extending the natural vibration period of showcases; ease the seismic response transmitted to collections and thus ensure the safety of collections.
(2) Independent Showcases

As for precious museum collections, the anti-seismic solution targeted at both showcases and collections is adopted. The anti-seismic device is installed at the bottom of an independent showcase, which is connected with the upper board of the anti-seismic device; it avoids the peak energy frequency band of earthquake, eases seismic response and thus protects collections from earthquakes. The diagram of seismic protection for independent showcases is shown in figure 4.

![Figure 3. The diagram of seismic protection for large showcases.](image)

(a) Seismic protection for exhibit stands Collections; Anti-seismic devices
(b) Seismic protection at the bottom of a showcase

![Figure 4. The diagram of seismic protection for independent showcases Collection.](image)

(3) Exhibition Appliances

In Yunnan Provincial Museum, the seismic protection solutions for exhibition appliances focus on the application of technical measures and auxiliary items, such as sticking, getting stuck, fixing or binding collections. Such measures are generally arranged based on the needs of exhibitions, and are the most frequently used, must-use and effective anti-seismic means in museums. They shall receive great attention in museum exhibitions, and relevant staff shall improve seismic protection awareness and technical levels to prevent damage from happening.

2.3. Anti-Seismic Technologies in Yunnan Provincial Museum

Yunnan Province lies on the eastern side of the edge of the world's most active collision zone between Indian Ocean plate and Eurasian plate, where seismic activities are frequent. Yunnan Province and seismic actions will pose threat to museum collections, site selection is critical. To provide seismic protection for museum buildings in the region characterized by anti-seismic intensity 8 (0.2 g), seismic group III and site category III, the technology isolates seismic energy at foundation is adopted.

The seismic isolation technology for building structures can’t fully ensure the safety of all the precious collections in the museum. So, seismic protection for the precious and fragile collections in
the museum was improved. The effect picture of the intelligent anti-seismic showcase whose installation is completed is shown in figure 5. When there is earthquake action, the anti-seismic devices will start to extend the natural vibration cycle of showcases or collections and ensure the safety of museum collections.

(a) An intelligent anti-seismic showcase  
(b) Large independent anti-seismic showcases

Figure 5. The effect picture of intelligent anti-seismic cabinets.

3. Analysis of Dynamic Response Based on the Seismic Protection for Museum Collections

3.1. Selection of Seismic Waves
According to the dynamic time-history analysis of Yunnan Provincial Museum based on Paragraph 3 of Article 5.1.2 in the Code for Seismic Design of Buildings (GB50011-2010) (2016 Edition), and taking into account the characteristics of seismic isolation structures and non-seismic isolation structures of Yunnan Provincial Museum, seven seismic waves were finally selected, including five natural seismic records and two artificial seismic records. The seismic influence coefficient deviations of the selected seismic waves on the main periodic points of the seismic isolation structures are all below 20%, so, the selected seismic waves meet anti-seismic standards.

According to the seismic safety evaluation report for the project site of the new hall of Yunnan Provincial Museum and Yunnan Provincial Culture and Art Center [11], we adjusted the accelerated speed in time-history records based on the acceleration peak in event of an 8-intensity (0.2 g) rare earthquake, and defined the acceleration peak as 400 gal.

3.2. Model of the Overall Structure of the Museum Building
The main structure of the Yunnan Provincial Museum is 39 m tall, with five levels above the ground and two levels under the ground, and the floor size is 104 m*104 m. Seismic isolation design is provided for the main structure. The seismic isolation layer is arranged between B1 and B2. The steel reinforced concrete framework is adopted above the seismic isolation layer, while the cast-in-place reinforced concrete structure is adopted below seismic isolation layer.

Yunnan Provincial Museum was designed before 2010 based on the Code for Seismic Design of Buildings (GB50011-2001) (2008 Edition). To ensure the reliability of the overall structure analysis and the seismic protection design for collections, this paper refers to the latest anti-seismic code, Code for Seismic Design of Buildings (GB50011-2010) (2016 Edition), when analyzing the overall structure of the museum, and updates relevant seismic parameters in the original design to anti-seismic intensity 8 (0.2 g), site category III, design earthquake group III and site characteristic cycle Tg=0.65 s for verification to make the analysis results more reliable (figure 6).
3.3. The Accelerated Speed of the Floors of Exhibition Halls

We conducted dynamic time-history analysis using the MIDAS/GEN (V8.3.6) software. We input the said seven seismic waves, and calculated the acceleration response peaks of all floors in the earthquake. Let’s take the response of the floor of 2/F under Artificial Wave 1 for example. The acceleration response curve and spectrum curve of the floor are shown in figure 7. As the predominant frequency of the floor of 2/F is 0.53 Hz, and the acceleration peaks of different locations of the same floor are similar as overall seismic isolation is adopted for the structure, the maximum accelerated speed of the floor under Artificial Wave 1 is 113.2 gal, and the minimum accelerated speed is 110.7 gal.

![Figure 7. The acceleration time-history and corresponding frequency spectrum curve of 2/F.](image)

3.4. Anti-seismic Analysis and Design for Museum Collections

Let’s take large independent showcases for example and introduce anti-seismic design and implementation. In the exhibition hall on 2/F above the ground, each large independent showcase (W*L*H=800 mm*2500 mm*2700 mm) is equipped with two anti-seismic devices at the bottom. We used MIDAS/GEN (V8.3.6) to build a finite element model of the large showcase, simulating the anti-seismic devices with springs and dampers. We input the acceleration response time-history data for the floor of 2/F above the ground of the museum for dynamic time-history analysis.

We defined the technical parameters of the anti-seismic device of the large showcase as follows: the natural vibration frequency of the showcase is 1.337 rad/s; if the damping ratio is 20% and two anti-seismic devices are installed at the bottom of the large showcase, the stiffness of each anti-seismic device is 741.63 N/m, and the damping is 332.86 Ns/m.

The acceleration and displacement response of the anti-seismic large showcase are shown in table 1. With input of five natural records and two artificial records, the average acceleration response decreases to 72 gal, the average seismic mitigation ratio reaches 34.21%, and the average displacement response (device stroke) is 212 mm, meeting the anti-overturning and anti-sliding requirements for showcases and collections in earthquakes.
Table 1. The acceleration and displacement responses peak of the anti-seismic large showcase.

| Floor wave | The acceleration response of the floor/gal | The acceleration response of the showcase/gal | Seismic mitigation ratio | Maximum displacement/mm |
|------------|------------------------------------------|---------------------------------------------|-------------------------|-------------------------|
| Artificial wave 1 | 112                                      | 89                                          | 20.5%                   | 322                     |
| Artificial wave 2 | 121                                      | 102                                         | 15.9%                   | 327                     |
| Imp178      | 123                                      | 98                                          | 20.5%                   | 239                     |
| San_68      | 97                                       | 73                                          | 24.9%                   | 209                     |
| Sup_719     | 101                                      | 39                                          | 61.0%                   | 133                     |
| Sup_724     | 95                                       | 56                                          | 41.5%                   | 144                     |
| TAFT        | 105                                      | 47                                          | 55.4%                   | 111                     |
| Average value | 108                                      | 72                                          | 34.2%                   | 212                     |

4. Conclusions
The paper focuses on the research on and demonstration application of anti-seismic technologies in Yunnan Provincial Museum. The main conclusions are as follows:

(1) It summarizes the anti-seismic technological means that take into account seismic waves, museum buildings, exhibition facilities (showcases) and collections, which are applicable to all museums;

(2) As the overall seismic isolation structure is adopted for Yunnan Provincial Museum, the acceleration of floors significantly decreases under seismic actions, and the acceleration peaks of different locations of the same floor are similar;

(3) As the seismic isolation system adopted in the museum building can't ensure the safety of all collections, procurement of standard products is not advisable, and anti-seismic analysis and anti-seismic parameter design need to be conducted for the collections in different showcases based on the seismic response of the museum structure;

(4) The acceleration response time-history data of the museum floors in rare earthquakes are input to conduct dynamic time-history analysis for showcases and large showcases and design parameters for anti-seismic devices, which produces good vibration mitigation results and meets the anti-overturning and anti-sliding requirements for museum collections in rare earthquakes;

(5) As demonstration practice, the seismic effect monitoring system was installed in the seismic isolation layer, in the hope that the monitored data can provide scientific quantifying basis for the optimization of the anti-seismic technologies for museum collections.

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