Preventive Seismic Protection Technologies to Museum Collections: Quanzhou Museum of China Case Study

Jie Qin, Botao Ma*, Maomao Song, Mansheng Zhang, Zhizhong Guan, Ling Zhang and Jiaqi Ge
China Aviation Planning and Design Institute (Group) Co., Ltd., No.12, Dewai Street, Beijing, 100120, People’s Republic of China

*Corresponding author email: mabotao@avic-capdi.com

Abstract. The destruction of museum collections caused by earthquakes in China has attracted many scholars' attention. Taking the implementation of the project of Quanzhou Museum for example, this paper introduces the application of the preventive seismic protection technologies to museum collections in aspects like the seismic design method, the verification of the performance of the anti-seismic products for showcases and museum collections, the implementation and effects of anti-seismic products. Through the implementation of the seismic protection and monitoring system for museum collections, an effective long-term mechanism for the seismic protection of museum collections in Quanzhou Museum is proposed. Finally, the successful demonstration of the preventive conservation of museum collections in Fujian is summarized.

Keywords: Museum; Seismic protection; Museum collection; Seismic monitoring; Preventive conservation.

1. Introduction
Under the influence of two major seismic belts in the world, the seismic fault zones in China are very developed. Obviously it is urgent to improve the holistic seismic capacity of the country, especially seismic protection of museum collections has attracted more attention in recent years. The researches on the preventive conservation of museums developed early in the US and Japan[1]. In China, with the development of the cultural heritage undertakings during the 13th Five-year Plan period, some technological progress has been made in the preventive conservation of museum collections, and practices have been seen in Yunnan and Sichuan.

As Quanzhou is prone to earthquakes, preventive conservation of museum collections is needed urgently. By applying related experiences and results both at home and abroad[2-4], guiding by the idea of systematically solving the seismic problem for museum collections, rooting in “seismic wave + buildings + exhibitions + showcases + collections” comprehensive plan, a research aimed at seismic protection of Quanzhou Museum collections is studied, and an effective and long-term preventive mechanism with the seismic monitoring system is established. This project represents the first practice of such studies in the southeast coastal region.

2. Overview of Earthquakes in Fujian
Fujian is on China's southeast coast, locating in the northern part of the Southeast Coastal earthquake zone. Data shows that from May 963 to December 2019, Fujian saw 41 earthquakes with 4.75 magnitude
or above (including Nan’ao island): the epicenter of only six earthquakes was located north of 26 ° N, and 35 times south of 26 ° N, accounting for 85%; earthquakes above 6 magnitude all happened in southern Fujian, and strong tremors were easily felt because of the shallow focal depth. Taiwan Strait, facing Fujian, is one of the earthquake zones with the most active seismic activities in the world, and several highly destructive earthquakes had occurred there in history. Each of the earthquakes that occurred in Taiwan Strait would spread to Fujian, causing huge damage to Fujian. Historically, there were two periods with notable seismic activities in Fujian, i.e. the period from 1445 to 1691 and the period from 1791 to present. There was a quiet period that lasted for nearly a century (1692-1790) between the two said periods. Each cycle of an earthquake includes four stages of response, i.e. the stage of accumulation, the stage of accelerated release, the stage of massive release and the stage of residual release. At the current stage, the seismic activities in Fujian are right at the last stage of the second cycle. The structure and distribution of strong earthquakes in Fujian are shown in Fig. 1.

![Figure 1. Structure and distribution of earthquakes in Fujian Province.](image)

Quanzhou, locating in southeastern Fujian, is an earthquake prone coastal city, where the seismic fortification intensity is 7.5 degrees. On December 29, 1604, an M 8 earthquake took place in the sea area east of Quanzhou, which was the biggest one ever seen in the southeast coast region, causing severe damage to the coastal area of Fujian. Quanzhou-Shantou seismic belt is of the highest level of seismicity in the southeast coastal seismic sub-regions, and from 1067 to 1976, a total of one M 8 earthquake, two M 7-7.3 earthquakes and six M 6-6.9 earthquakes were recorded here.

3. Preventive Conservation of Museum Collections for Seismic Protection
The new hall of Quanzhou Museum was completed and opened to the public on the New Year’s Day of 2005. Located on the northern side of the West Lake, at the foot of Qingyuan Mountain, the new hall covers 55,000 m² of land and over 16,000 m² of floor area, including 6,500 m² of exhibition area and 900 m² of storage area. It is a comprehensive museum with the architectural style of southern Fujian, where the World Multi-culturalism Exhibition Center set up by UNESCO is located. In 2008, it was rated as a Grade II museum at the State level. Given the seismic characteristics in Quanzhou, preventive conservation is studied and implemented for the collections in Quanzhou Museum in a systematical way. The effect drawing of Quanzhou Museum is shown in Fig. 2.
3.1. Research on the Seismic Protection Design for Museum Collections

As a newly built building, the museum was designed under relevant anti-seismic requirements, possessing certain anti-collapse capability in fortification earthquakes. However, seismic acceleration responses are different at different locations on the floor, which is amplified layer by layer through the coupling effect of floor transmission, so the acceleration response is regarded as master factor of causing damage to exhibitions (showcases) and museum collections. To better protect the collections in Quanzhou Museum from earthquakes, given the impossibility of reconstructing the original anti-seismic protection buildings into seismic protection (vibration isolation) buildings, the emphasis is put on the seismic protection of exhibitions (showcases) and museum collections to mitigate or stop the earthquake acceleration response of floors. Through evaluation of collection safety and confirmation by experts, the objectives of the seismic protection design for museum collections are set below: under 7-degree fortification intensify (0.15g), the 3rd seismic group, Category II site land and 0.45s characteristic site period, the reduction rate of the earthquake acceleration response of floors shall not be lower than 75%, and in combination with traditional protection measures, efforts shall be made to protect exhibitions (showcases) and collections from overturning or sliding and ensure the seismic protection performance of exhibitions (showcases) and collections[6-8].

The objects of this seismic safety assessment are Quanzhou historical and cultural exhibition hall and Fujian Taiwan history exhibition hall, located on the second and third floors of Quanzhou Museum respectively. In this paper, the finite element analysis software YJK (v1.8.1.1) and MIDAS/Gen (v8.3.6) are used to establish the finite element model of the museum's overall structure, meanwhile the connection between the main structure and the mounted showcases is simulated to reflect the influence of the status of these showcases on the exhibiting cultural relics. The simulation conditions include five records about natural earthquakes and two records about artificial earthquakes. Through the seismic dynamic simulation, the dynamic periodic response of each exhibition hall is obtained, and the results are compared and analyzed. The sketch map of the 3D analysis model is shown in Fig. 3, and the finite element model-based data comparison is shown in Table 1.

### Table 1. FEM-based comparison.

| Period/s | YJK  | MIDAS/GEN | Error |
|----------|------|-----------|-------|
| T1       | 1.01 | 1.019     | 0.7%  |
| T2       | 0.98 | 1.00      | 2.0%  |
| T3       | 0.79 | 0.80      | 1.3%  |

The comparative analysis shows the dynamic period errors of the two structural models are within 5%, which meets accuracy requirements, and the correctness and applicability of the models of the seismic design for the showcases is verified.
According to the *Specification for Seismic Protection of Museum Collection* (hereinafter referred to as WW/T 0069-2015)[9,10], the seismic safety of museum collections is subject to the dynamic response under seismic action, and the dynamic coupling amplifying effect exits between seismic vibration-museum halls, museum halls-showcases, and showcases-museum collections. So, a systematic method of “earthquake vibration-showcases-museum collections” is adopted in earthquake action analysis and personalized safety design of the seismic protection showcases. Seismic protection is provided at the bottom of showcases. According to the earthquake situation of Quanzhou Museum site and the calculation results of finite element model, considering exhibits inside, the parameters of the seismic protection devices are designed. Sketch map of the seismic protection showcases is shown in Fig. 4

![Figure 3. MIDAS/GEN finite element model.](image)

![Figure 4. Sketch map of the seismic protection showcases. [Unit: mm](image)]

### 3.2. Verification of the Seismic Protection Performance of Exhibitions (Showcases) and Museum Collections

Based on the demand of the museum, No.1~No.4 Exhibition Hall of Quanzhou’s history and culture exhibition on the 2nd floor is equipped with Twenty-one seismic protection central showcases; Unit 3 of the exhibition hall of the history of Fujian and Taiwan on the 3rd floor, which is about the spread of southern Fujian culture, is provided with five seismic protection intelligent showcases.

A seismic protection showcase has two typical sizes, including 0.8m×0.8m×2.2m(H) and 0.9m×0.9m×2.2m (H), the height-to-width ratio of an independent showcase is bigger than 1.5. To prevent exhibits from overturning or sliding under rare or very rare earthquake actions, a proper damping ratio and corresponding rigidness are set for the seismic protection devices, so as to ensure a natural vibration period which is not less than 1.5 times of the predominate period of the hall structure.

Take the seismic protection central showcase for example, through finite element analysis, the acceleration and displacement responses of the showcase were got: the natural vibration period of the seismic protection device 2.8s, the average acceleration response 38.8gal, and the average displacement 47mm, meeting the design requirement of an extreme displacement of 190mm. Moreover, it vibrates horizontally in the first two phases without any twisted vibration, proving that the seismic protection device has double horizontal seismic isolation capability. The cloud picture of the acceleration response of the showcase under earthquake action is shown in Fig. 5, and the displacement response is shown in Fig. 6.
3.3. Implementation and Product Effect of Exhibitions (Showcases) and Seismic Protection Devices

To scientifically verify the effectiveness of seismic protection devices, the research team organized the following reasonable and effective installation and commissioning at the site in early January 2019: 1) When the seismic protection devices were transported to the site, it detected the appearance of springs and dampers as well as the location, elevation and levelness of each device; 2) it tested the rigidity of each device under the push that caused 100mm and 150mm of displacement, and compared the results with the design parameters, confirming the error was within 5%; 3) it tested the pushing force and rigidity of a 200kg showcase connected with a 180kg seismic protection device through bolts, and compared the results with the design parameters, confirming the error was within 5%. Monitoring of the seismic protection devices at the site is shown in Fig. 7.

Through installation of seismic protection devices for exhibitions (showcases) and museum collections, reconstruction of the independent showcases in the target location was basically completed. That extends the natural vibration period of exhibitions (showcases), reduces the impact of earthquakes on museum collections, and thus meets the seismic protection requirements for museum collections in the region. The effect of the reconstructed exhibitions (showcases) in the exhibition hall on the 3rd floor is shown in Fig. 8.
4. Overview of the Seismic Monitoring System for Museum Collections
As Fujian is prone to earthquakes, it’s necessary to conduct a long-term mechanism for seismic protection of museum collections. A corresponding seismic monitoring system and seismic protection device monitoring system is provided for the museum, who works as: to be in permanent protection preparation state before earthquakes, to start promptly and work normally in earthquakes, and to report seismic protection conditions after earthquakes[11,12]. Composition of the seismic monitoring system is shown in Fig. 9.
4.1. System Composition

To accurately and effectively evaluate the impact of the seismic force on buildings and museum collections, the seismic monitoring system introduces nine sets of ultra-low-frequency three-way seismic acceleration sensors and three sets of ultra-low-frequency three-way seismic speed sensors to collect vibration data. Based on the characteristics of museum buildings and collections in display, data collection terminals are unevenly distributed in the exhibition halls on the 2nd and 3rd floors through two control means, i.e. combining acceleration sensors with speed sensors and combining building monitoring with collection monitoring. To ensure the real-time recording of the dynamic response of the seismic protection devices and museum collections in earthquakes and record the motion of museum collections, three sets of video monitoring devices of different types are provided in key demonstration areas based on the characteristics of exhibition halls and museum collections. The layout of the seismic monitoring terminals is shown in table 2.

Table 2. Layout of seismic monitoring terminals.

| No. | Detailed location                                                                 | Device name                        | Quantity |
|-----|-----------------------------------------------------------------------------------|------------------------------------|----------|
| 1   | In the showcase of the celadon chamber pot and at the corner of the wall behind the | Three-way acceleration sensor      | 2        |
|     | showcase in No.1 Exhibition Hall on the 2nd floor                                 |                                    |          |
| 2   | At the corner of the wall behind the showcase of the celadon jue in the No.1      | Three-way acceleration sensor      | 1        |
|     | Exhibition Hall on the 2nd floor                                                   | Three-way speed sensor             | 1        |
| 3   | Inside and on top of the showcase of silkworm cocoons in No.2 Exhibition Hall on  | Three-way acceleration sensor      | 1        |
|     | the 2nd floor                                                                      | Vibration video monitoring device  | 1        |
| 4   | Inside the showcase of the copper Xuantian Emperor, at the corner of the wall     | Three-way acceleration sensor      | 2        |
|     | behind the showcase and on top of the showcase in No.3 Exhibition Hall on the 2nd | Vibration video monitoring device  | 1        |
|     | floor                                                                             |                                    |          |
| 5   | Inside the TV cabinet of the sculpture of Zheng Chenggong in No.4 Exhibition      | Three-way acceleration sensor      | 1        |
|     | Hall on the 2nd floor                                                             |                                    |          |
| 6   | At the corner of the wall behind the showcase of the blue and white porcelain in  | Three-way speed sensor             | 2        |
|     | No.4 Exhibition Hall on the 2nd floor                                              |                                    |          |
| 7   | Inside the showcases, at the corner of the wall behind the showcases and on top  | Three-way acceleration sensor      | 2        |
|     | of the showcases on the 3rd floor                                                 | Vibration video monitoring device  | 1        |

Besides the comprehensive and effective distribution of seismic monitoring terminals, special GB-level wired cables are also used to transmit seismic frequency data to switchboards in a special room through gateways, relays and bridges; the switchboards transmit signals to data and application servers for classified processing, which store information database in hard drive cameras while presenting the data to front-end customers through human-computer interaction software and supporting customers in searching the information they need at any time, so as to evaluate the impact of factors like the building structure, exhibition facilities and seismic protection measures on the seismic safety of museum collections and finally improve the preventive conservation capability for seismic protection.
4.2. System Tests
Seismic monitoring products serve customers mainly through human-computer interaction software. The monitoring system platform adopted here features functions like monitoring point and parameter setting, professional data analysis, table or graphic display, real-time alarming, historical data inquiry, correction formula setting, offline detection data logging. Moreover, the system will automatically delete the historical data more than three months ago to improve server inquiry and processing rates. In the video monitoring system, the video signals of front-end cameras are connected with the embedded hard drive video recorders to ensure videos to be kept for more than 15 days and facilitate future investigation and evidence collection. The interface of the vibration monitoring system is shown in Fig. 10, and the effect picture of this system is shown Fig. 11.

![Figure 10. The interface of the vibration monitoring system.](image1)

![Figure 11. Picture of the video monitoring of vibration.](image2)

5. Summary
The preventive conservation research on the seismic mitigation and seismic monitoring for Quanzhou Museum includes three stages:
(1) At the preliminary investigation stage, the seismic conditions in Fujian and Taiwan Strait are collected and studied, then the feasibility and necessity of the preventive conservation project for Quanzhou Museum is analyzed by the project team, and based on the current conditions of the buildings of Quanzhou Museum and the characteristics of museum collections, a preliminary seismic protection plan for the museum collections was taken out.
(2) At the stage of project implementation, based on the preliminary research results and relevant experiences, following codes like the WW/T 0069-2015, the seismic protection plan for the collections in Quanzhou Museum was detailed. Meanwhile, a personalized design for the seismic protection products was raised, in aspects like design objectives, design methods and personalized performance, and rigorous tests and parameter verification were conducted at the site to ensure the effectiveness of products; a seismic monitoring system was also equipped to improve seismic protection warning and evaluation, so as to achieve the ability of seismic safety of collections in Quanzhou Museum.
(3) After the preventive conservation project was implemented, seismic protection strategies are adjusted and improved based on the daily maintenance of seismic protection products, collection and analysis of data on the seismic monitoring platform and real-time monitoring of the seismic protection state of museum collections, so as to improve the preventive conservation for the collections in Quanzhou Museum.

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