International Journal of Civil Engineering and Machinery Manufacture

Volume 4, Issue 1, March, 2019

Publisher: HongKong New Century Cultural Publishing House
Address: Unit A1, 7/F, Cheuk Nang Plaza, 250 Hennessy Road, Wanchai, Hong Kong
Tel: 00852-28150191
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Contents

Research on Seismic Protection of Stone Cultural Relics Based on Seismic Isolation Technology

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Abstract: Damages to important cultural heritages in the museum during earthquake has attracted the attention of heritages conservation workers. Seismic isolation technology provides a new research direction for seismic protection of cultural heritages. Firstly, the critical conditions for the movement of cultural relics during earthquakes are discussed. Secondly, the composite seismic design of "stone pedestal + isolation bearing" is proposed. Finally, the application of isolation technology to the peristele is discussed, which shows that the seismic isolation technology can effectively reduce the probability of the peristele's overturning damage.

Keywords: Seismic protection of cultural relics; Overturning failure; Design of seismic isolation; Seismic performance

1. Introduction

Museums have a large number of cultural relics with free-standing, so it is of great significance to study the seismic protection methods of cultural relics floating on the ground (Fig.1). The antiseismic protection is usually carried out by reducing the center of gravity, bonding, supporting [1]. Three types of destruction usually occur when a cultural relic is subjected to an earthquake [2]. The first type is that the cultural relic's material is too weak to break. The second type is the destruction of the cultural relics by the external force or the overturning ; The third type is the destruction of the cultural relics caused by the secondary disasters caused by the earthquake. Floating cultural relics are often subject to first or second damage.

Although there is no serious damage to the museum structures under the high intensity earthquakes, the cultural relics in the museums are at risk of serious damage. The extremely destructive nature of earthquakes is putting forward a severe test for the protection of cultural relics against earthquakes, and the isolation technology provides a new research direction for the protection of cultural relics against earthquakes [3]. Isolation technology(Fig.2) is a mature technology in building reinforcement and post-disaster reconstruction. The vibration test of traditional methods of hertages protection is carried out in [4] [5]. The results show that the methods can prevent earthquakes when the earthquake intensity is less than 110 gal, but the risk of damage is still existing when the intensity is high. [6] compared the traditional methods of antiquakes with the methods of isolation, and pointed out that the isolation of antiquities has a wide application prospect in earthquake resistance. [7] had carring out the analysis of the earthquake excitation of statues simplified as rigid bodies under multiple factors. It is concluded that the destruction of stone sculptures is mostly caused by overturning or partial fracture. According to the characteristics of Shanghai surrounding sites, [8] focused on the acceleration amplification effect of Shanghai Museum by using the layer mode; Based on the statistical principle, [9] proposed a simple dynamic amplification algorithm for the number of floors.

Firstly, the critical conditions for the movement of cultural relics during earthquakes are discussed in present papaer. Secondly, the composite seismic design of "stone pedestal + isolation bearing" is proposed. Finally, the application of isolation technology to the peristele is discussed, which shows that the seismic isolation technology can effectively reduce the probability of the peristele overturning damage.

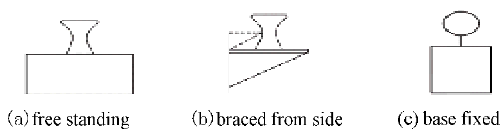

Figure 1. The support categories of cultural relics

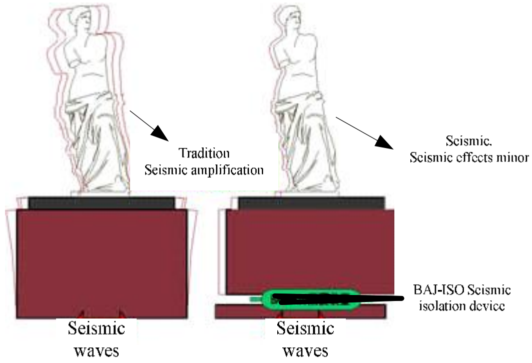

Figure 2. The diagram of isolation

2. Movement of Stone Peristele under Earthquake

The stone peristele shown in figure 3 is the object of protection against the earthquake, and its parameters are shown in Table 1. Because the similar stone relics have different degrees of earthquake damage in the past earthquakes, the local civil insurance organization plan to move into the indoor and take earthquake prevention. The main motion forms of stone columns during earthquake occurrence are slip and overturn. According to the Chinese Code <Specification for seismic protection of museum collection >, the critical acceleration of slipping is 1.75 m/s2 when the horizontal seismic is considered independent. The critical acceleration of overturning is 1.1m/s2. The overturning is shown in figure 4.

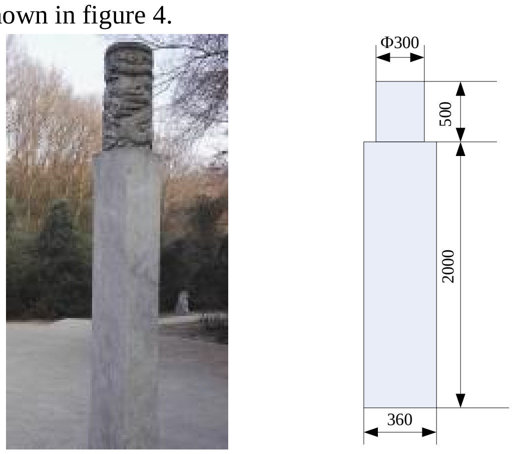

Figure 3. The schematic photograph of stone cultural relic

3. The Intensity of Seismic Excitation

The stone peristele exhibition hall is a three-story reinforced concrete structure. The seismic site type is II, the site characteristic period is 0.35s, the seismic fortification intensity is 7 degrees in china, and the design basic seismic acceleration is 0.15g. Without considering vertical seismic action, the comparison of floor response spectrum based on site design response spectrum and EL(el-centro) wave is shown in figure 5. Under rare earthquake, the peak acceleration of design floor response spectrum is 1.44g. Under the seismic of EL wave, the peak acceleration is 1.53g. Therefore EL wave is suitable for analysis. With the increase of floor, the effect of horizontal seismic acceleration amplification is obviously enhanced, so it is suggested that the stone peristele should be placed on the first floor.

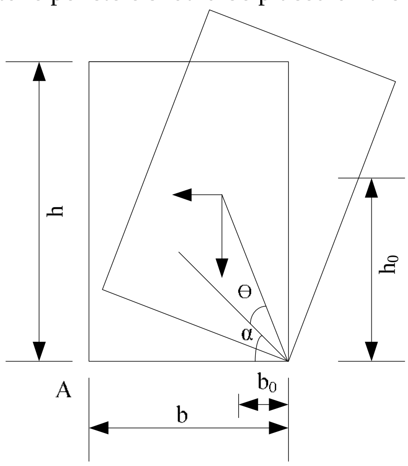

Figure 4. The photograph of overturning

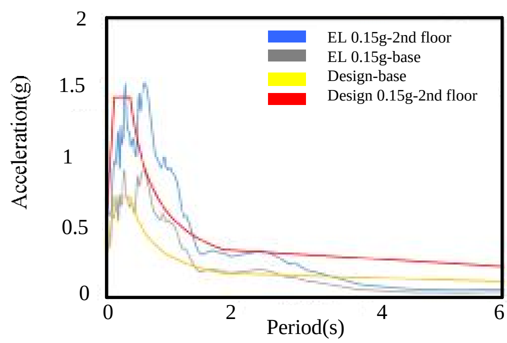

Figure 5. The curve of response spectrum

4. Seismic Protection Design of Stone Peristele

Considering that the stone-column is to be placed on the first floor, if the side support reinforcement is adopted, the space is large and the viewing effect is affected, so the combined anti-seismic measures with the "stone pedestal + isolating bearing" are considered.

4.1. Design of the stone pedestal

Firstly, adding stone pedestal is used to debase the center of gravity of the stone peristele. The stone pedestal adopts the same slate as the stone peristele, and two kinds of specifications are used to compare the effects (Table 2). The stone pedestal chiseling the 30mm deep subsidence (figure 6a/b). The original stone column and the pedestal are bonded with non-corrosive unsaturated epoxy resin binder, which can be regarded as rigid connection between the stone column and the stone base. When the stone column is simplified into a rigid body, the ratio of height to width is reduced from 6.3 to 4.3, and the critical acceleration of overturning is 1.4 times higher than that without the pedestal(adding pedestal 1). The ratio of height to width is reduced from 2.0 to 2.4, and the critical acceleration of overturning is 2.5 times higher than that with no pedestal(adding pedestal 2). The results show that the stone pedestal can effectively improve the anti-capsizing ability of the stone column.

4.2. Design of the isolation bearing

Assuming that the isolation coefficient is at least 0.35, the ratio of the dominant circular frequency of the site to the circular frequency of the stone column after the isolation, the equivalent damping ratio of the isolation is taken, and the total weight of the upper part is 1.1t.Therefore, the horizontal stiffness of the isolation device is calculated as 9 300N/m(about 10 000N/m), and the isolation coefficient η = 0.07, which is less than 0.35 of the design objective, in this condition the isolation period is 2.1s. The isolation device is planned to consist of four supports (fig.6c), each bearing horizontal stiffness being 2500N /m. Vertically is assumed as incompressible. The parameters of each isolation bearing is shown in Table 3.

Table 1. The parameters of stone relic

Model	Material	Length * Width * Height /(mm)	Density ($kg*m^{-3}$)	Elastic Modulus (GPa)	Poisson Ratio
Peristele	slate	360*360*2000(bottom) φ300*500(top)	2500	50	0.2

Table 2. The design parameters of stone pedestal

Number	Diameter *Height/(mm)	Mass/(kg)	Centre of gravity/(mm)	Depth-Width ratio	Overturn value /($m*s^{-2}$)
Pedestal 1	φ500*200	125	1080	4.3	1.67
Pedestal 2	φ800*200	320	960	2.4	2.92

Table 3. The design parameters of isolation bearing

Items	Yield stiffness/($N*m^{-1}$)	Yield force/(N)	Yield stiffness/ elastic stiffness	Yield force/ Weight	Quantities
Isolation bearing	2500	200	0.1	0.07	4

5. Analysis on Isolation Performance of Stone Relics

EL wave amplitude-modulated to 0.15g is used to calculate the time-history dynamics of the stone columns placed on the first floor. Because the horizontal dimensions of the stone columns are the same, one-side analysis is carried out. Comparison of acceleration at the center of gravity with different stone pedestal is shown in fig.7. Without stone pedestal ,the peak acceleration is 3.03m/s2.The peak value is 2.83m/s2 when the base 1 is added, and the peak value is 2.46 m/s2 when the base 2 is added. The acceleration response is 1.2times lower than that of the non-pedestal, which indicates that the acceleration response of the stone column can be reduced to a certain extent. The effect of reducing the acceleration with pedestal 2 is more obvious than with pedestal 1,because of pedestal 2's mass and width is more larger than pedestal 1.

The curve comparison of peak acceleration of the stone peristele between the condition with pedestal 2 and the condition with "stone pedestal 2+ isolation bearing" is shown in fig.8. The peak acceleration of the pillar is 3.13m/s2 when the base is fixed, at this point, the overturning failure of the stone statue has taken place. The peak acceleration with pedestal 2 only is reduced to 2.58 m/s2, which is 2.3 times less than that of fixed, but there is still a great risk of overturning. The peak acceleration of the stone column is 0.95m/s2 when the "stone pedestal+ isolation bearing" is adopted, which is 3.3 times less than that of the base fixed, and 2.7 times less than that of the only additional pedestal 2, which does not reach the critical value of overturning and slipping. Therefore, the stone peristele is considered to be in a safe state. Figure 9 shows the response spectrum of acceleration and displacement at the top of the stone column during isolation. For the period after 1s, the peak response acceleration is less than 1.1m/s2, which satisfies the anti-overturning requirement. The peak displacement of the stone column appears in the 2.8s periodic attachment with a value of 55 cm. Enough horizontal displacement space should be considered around the stone pedestal in the exhibition museum.

The comparison of the acceleration response spectra between isolated and non-isolated is shown in Fig.10. If the periods is more than 1Hz, the acceleration reduction effect of the isolation device is better. If the periods is between 0.1Hz and 10Hz, the isolation is disadvantageous to the protection of cultural relics. Therefore, structural period and post-isolation period should be considered at the same time for isolation design of cultural relics.

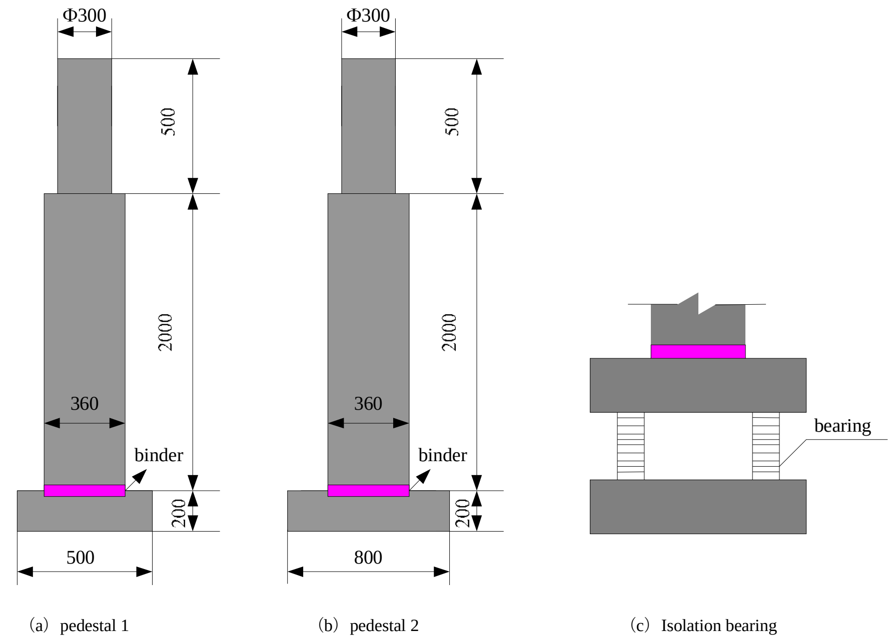

Figure 6. The schemes of base and seismic isolation

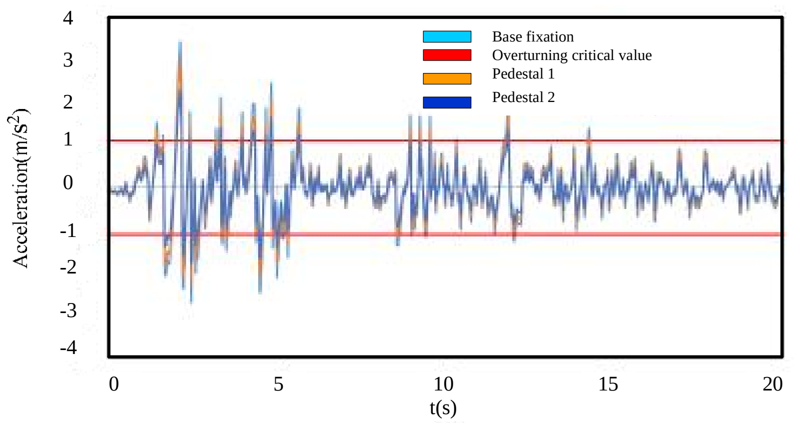

Figure 7. The top acceleration curves of time history with adding pedestal

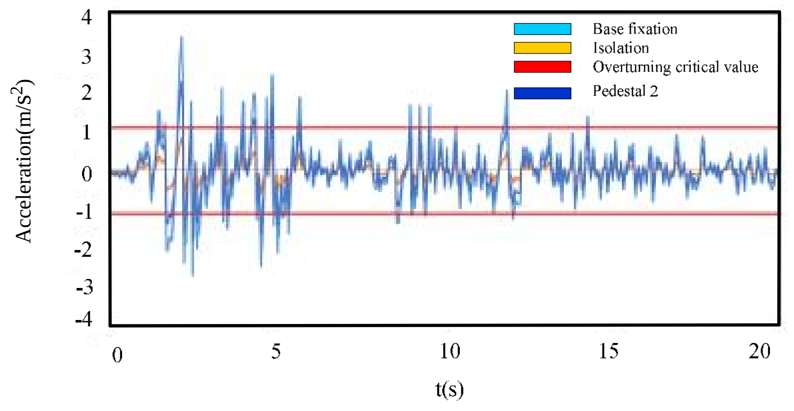

Figure 8. The top acceleration curves of time history with adding pedestal and isolation bearing

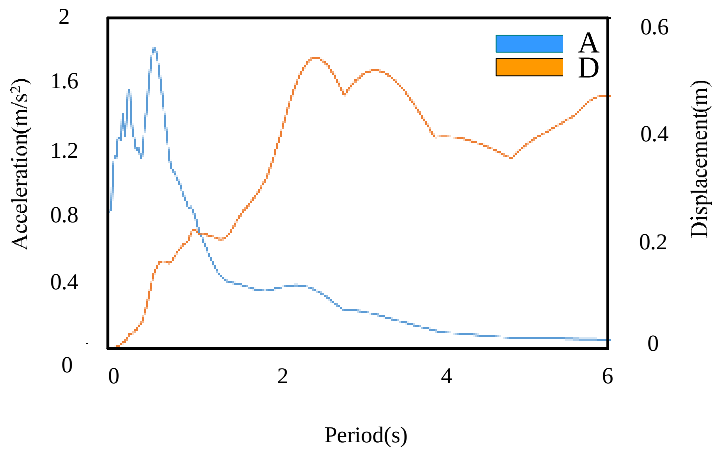

Figure 9. The Response spectrum of top acceleration and displacement with isolation

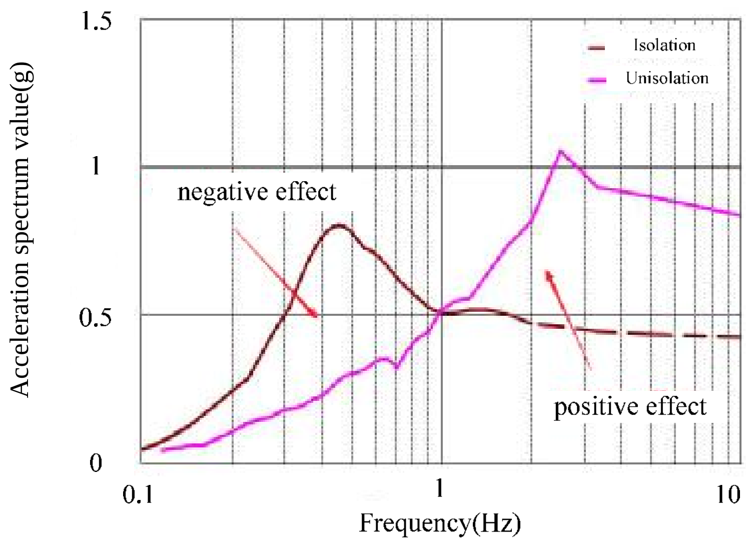

Figure 10. The comparison of acceleration response spectrum

6. Conclusions

In present paper, the seismic reinforcement design and performance analysis of stone relics with a ratio of height to width of 6 are carried out based on isolation technology. The conclusions are as follows:

Considering the effect of floor amplification, The probability of overturning damage of the cultural relics is higher, so it is difficult for the traditional earthquake prevention measures to deal with the overturning risk effectively.

Although the pedestal can reduce the center of gravity of the stone relics and the acceleration response of the peristele, but the application of the important cultural relics is limited, it is necessary to adopt the seismic isolation design.

The application of isolation technology can effectively reduce the acceleration response and the probability of earthquake overturning of stone relics. But the horizontal direction of cultural relics should have enough movement space, and the corresponding isolation bearings should be developed.

7. Acknowledgment

The support provided by the Project of Henan Private Education Association (HMXL-20180046) is gratefully acknowledged.

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