Asymmetric Village and Town Ancient Architecture Style Protection Based on the Historical Feature Sequential Logic

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Abstract
The asymmetric village and town ancient architecture, due to unique structural features, has anti-seismic performance different from modern architecture. Based on the stress performance and landscape destruction shape under horizontal earthquake effect, this paper gives ancient architecture style protection based on the historical feature sequential logic, takes the style of the pillars “swinging pillar”, and the style of bracket set layer “shear bending bar”: according to the style protection and the whole ancient architecture mass distribution conditions, it combines component test and the theory of style deduces the calculation method and the applicable scope of each parameter under the different stress conditions of style protection, and makes comparison with the shaking table test results. The results show that the proposed ancient architecture style protection based on the historical feature sequential logic can well reflect the style protection of the asymmetrical ancient architecture under the effect of an earthquake.

Keywords: Village and Town Ancient Architecture, Historical Feature, Sequential Logic, Style Protection.

1. INTRODUCTION
Asymmetric traditional village and town ancient architecture are the most existing and complex ancient architecture forms in our country(Krus, Cook, and Hamilton, 2015). This ancient architecture not only has a unique structure but also has good anti-seismic performance(Sutherland, Toy, Townend, Cox, Eccles, Faulkner, Prior, Norris, Mariani, Boulton, Carpenter, Menzies, Little, Hastings, De Pascale, Langridge, Scott, Reid Lindroos, Fleming, and Kopf, 2012; Neves and Haldenby, 2015). In terms of construction, it does not need a nail or a wedge. The beam and column nodes are all connected by a semi-circular tenon and mortise, and the post and the column are suspended on the foundation stone, the framework is divided into a basement, pillar support, paving, and roof layer from the bottom to the top (Leahy, Zhou, Vasile, Okonomopoulos, Schwager, and Belta, 2016; Wongpiromsams, Topcu, and Murray, 2012; Liu, Ozay, Topcu, and Murray, 2013); in the anti-seismic performance of ancient architecture, the energy dissipation and seismic reduction of the tenon joints, the frictional and lag seismic isolation and reduction of the plinth, and deformation energy dissipation seismic reduction of the chess paving layer (Alechina, Bulling, Logan, and Nguyen, 2017; Ding, Smith, Belta, and Rus, 2014), well reflect the anti-seismic idea of “hardness and softness, overcoming firmness by gentleness, seismic isolation by slip, seismic reduction by energy dissipation” in the asymmetrical ancient architecture (Yordanov, Tumova, Cema, Bamat, and Belta, 2012). In current times for greatly developing green ecological architecture and energy-saving architecture, it has a good guiding significance and reference for the development of seismic isolation, reduction, and control of modern architecture (Ito, Ichinose, Izumi, Izumi, Yonezaki, and Yonezaki, 2015).

It is precisely because of asymmetric village and town ancient architecture has a unique stress mechanism as well as seismic reduction and isolation performance; the existing ancient architecture style protection cannot really reflect its stress mechanism and style features. This paper mainly combines the characteristics including the deformation energy dissipation seismic reduction of the tenon joints, seismic reduction similar to “swinging pillar”, deformation energy dissipation of the chess paving layer, frictional and lag seismic isolation and reduction of the plinthetic: of asymmetric ancient architecture, establishes a style protection method that can reflect the seismic isolation and reduction performance of the asymmetrical ancient architecture, and verifies the rationality by comparing the results of the shaking table test for simulated earthquake of asymmetric traditional village and town ancient architecture done by the research group.

2. ASYMMETRIC TRADITIONAL VILLAGE AND TOWN ANCIENT ARCHITECTURE STYLE PROTECTION

2.1. Stress Mechanism of Ancient Architecture Under Effect of Horizontal Earthquake

The deep research on the friction-slip seismic isolation mechanism of the asymmetrical ancient architecture...
pin the establishes the friction-slip seismic isolation model of the column and the foundation stone and gives the judgment conditions of the column-foot slip. The results show that: when the seismic action strength increases to a certain extent, friction and slip occur at the column foot, some energy is dissipated through friction, and the natural vibration frequency of the ancient architecture is changed, thereby the style features of the ancient architecture under the action of strong earthquakes are changed so to play a seismic effect.

For the column section, the special tenon-mortise joints configuration (Figure 1) allows asymmetric ancient architecture to have characteristics different from those of modern architecture. Under the action of horizontal load, the semi-rigid tenon-mortise joints can produce a certain extrusion deformation with obvious hysteresis energy dissipation seismic reduction effect (Figure 2). Based on the shaking table test of the research group for whole ancient architecture, we can conclude that due to the flat pendulum of the column foot, the mutual restraint between the column foot and the base stone is relaxed, that is, the interface between the column foot and the base stone can resist pressure but has no resistance to tension, under the action of overturning moment, allows the column foot to have certain uplift at the interface with the base stone, under reciprocating horizontal load the column foot repeated lifting and reposition cause the pendulum swing, which reduces the ductility demand of pillar under strong earthquake, also decreases the earthquake damage.

Figure 1. Dovetail Structure

For bracket set paving layer, it can be seen from the whole ancient architecture shaking table test destruction conditions and four bracket sets coordinated work quasi-static test results (Figure 3) protection that: because of the characteristics such as the frictional energy dissipation between the capital block and the chap, steamed bun tenon curved extrusion deformation energy dissipation, shear extrusion deformation energy dissipation of tenon between block and chess, bending extrusion deformation energy dissipation etc. The bracket set paving layer has full energy dissipation hysteresis loop and obvious energy dissipation under the action of horizontal earthquake.

Figure 2. Dovetail Pillar Hysteresis Curve

Figure 3. Four Bracket Set Coordinated Work Pseudo-Static Test
2.2. Asymmetric Ancient Architecture Style Protection Methods

In the style protection of asymmetrical ancient architecture, combined with its stress mechanism and mass distribution, according to the two mass points asymmetric ancient architecture style protection model (Figure 4) do seismic response protection for the overall ancient architecture.

Asymmetric villages and towns are in the stage of elastic stress, no yield has occurred, the lower column has only lateral displacement, and only elastic deformation occurs in the bracket set paving layer, the equivalent model is shown in Figure 5 (a). According to Newton’s second law, the conditions for having no relative slip between column foot and base stone i.e. ancient architecture being in elastic work stage are:

\[ |\ddot{x}_g(t)| \leq \mu g \]  

(1)

Where: \( \ddot{x}_g(t) \) represents the ground acceleration; \( \mu \) is the maximum static friction coefficient between column foot and base stone; \( g \) is an acceleration of gravity.

3. ANCIENT ARCHITECTURE STYLE PROTECTION BASED ON HISTORICAL FEATURE SEQUENTIAL LOGIC

3.1. Establishment of Ancient Architecture Style Protection Model

For the ancient architecture style protection model based on the historical feature sequential logic, under the action of horizontal earthquake, before the slip occurs between the column foot and the bracket set paving layer, the ancient architecture is in a flexible working state: after the column foot and the bracket set paving layer have slipped, the ancient architecture is in a non-elastic working state, and the slip and deformation occur on the pillars as well as the bracket set paving layer. Figure 6 shows the stress protection diagram of two mass points at some moments of the asymmetric ancient architecture style protection model respectively. According to Newton’s second law, obtain:
\[
\begin{align*}
F + f_{d1} + f_{s2} - f_{d1} - f_{s1} &= 0 \\
f_{d2} + f_{s2} + f_{d2} &= 0
\end{align*}
\]

(a) Mass \( m_1 \) Instantaneous Stress Protection Map

(b) Quality \( m_2 \) Instantaneous Stress Protection Map

\[f_{d2} = C \ddot{x}_2(t)\]
\[f_{s2} = K_2 x_2(t)\]
\[f_{d1} = C_1 \ddot{x}_1(t)\]
\[f_{s1} = K_1 x_1(t)\]

\[F = \mu (m_1 + m_2) g \, \text{sgn} \left( \dot{x}_1(t) \right)\]

Figure 6. Asymmetric Ancient Architecture Style Protection Model Mass Point Instantaneous Stress Protection

Which is:

\[
\begin{align*}
&\left\{ \begin{array}{l}
m_1 \left[ \dddot{x}_1(t) + \ddot{x}_1(t) \right] + K_1 x_1(t) + C_1 \dddot{x}_1(t) - \\
\mu (m_1 + m_2) g \, \text{sgn} \left( \dot{x}_1(t) \right) - \\
C_2 \dddot{x}_2(t) - K_2 x_2(t) = -m_2 \dddot{x}_2(t) \\
m_2 \left[ \dddot{x}_2(t) + \ddot{x}_2(t) \right] + K_2 x_2(t) + C_2 \dddot{x}_2(t) = -m_2 \dddot{x}_2(t)
\end{array} \right. \\
\text{sgn} \left( \dot{x}_1(t) \right) = \begin{cases} 1 & \left( \dot{x}_1(t) \geq 0 \right) \\ -1 & \left( \dot{x}_1(t) \leq 0 \right) \end{cases}
\end{align*}
\]

Where: \( \dddot{x}_1(t) \) is the acceleration of ground horizontal motion; \( \ddot{x}_1(t) \) is the relative slip between the column foot and the base stone; \( \dot{x}_1(t) \) is the lateral displacement of the column frame; \( x_1(t) = H_1 \theta \), \( x_2(t) \) is the displacement of the roof layer relative to the column frame; \( m_1 \) is equivalent mass of the pillars, \( m_2 \) is the mass of the roof layer; \( K_1, C_1 \) are the equivalent anti-side stiffness and damping coefficient of the dovetail frame at different stress stages, is the equivalent anti-side stiffness and damping coefficient of the pavement, \( K_2, C_2 \) are the equivalent anti-side stiffness and damping coefficient of bracket set paving layer; \( \mu \) is dynamic friction coefficient between column foot and base stone; \( H_1 \) is the equivalent height of the pillars, \( H_2 \) is the height of the paving layer.

3.2. Determination of Ancient Architecture Style Protection Model Related Parameters

The parameters of the ancient architecture style protection model include: the equivalent mass \( m_1 \) of the column, the equivalent anti-side stiffness \( K_1 \) and damping coefficient \( C_1 \) of the swinging pillar, the equivalent
stiffness $K_2$ and damping coefficient $C_2$ of the bracket set style shear bending bar, and the dynamic friction coefficient $\mu_2$ between block and set. Dynamic friction coefficient $\mu_2$ can only be obtained through the experiment, the following is a discussion of solution method of other parameters.

The $m_i$ shall be the equivalent mass $m_e$ of the columns plus the mass $m_i$ of the columns, the equivalent mass of the column (Fig. 7) is determined on the principle of equal natural frequency of the first modeled body and the shear force of the substrate [8].

$$\sqrt{\frac{k_i}{m_i}} = \sqrt{\frac{k_{ii}}{m_e}}$$  \hspace{1cm} (5)

That is:

$$m_e = \frac{k_{ii}}{k_i} m_i$$  \hspace{1cm} (6)

So obtain:

$$m_i = m_e + m_e$$  \hspace{1cm} (7)

The equivalent anti-side stiffness $K_{ii}$ ($\text{kN} \cdot \text{mm}^{-1}$) of the lower column "swinging pillar" in different stress phases (elastic phase, yielding phase and failure phase) can be calculated by the formula (8) according to the single column “swinging pillar” Tanahashi restoring force model (Figure 8) proposed by literature [9].

$$K_{i1} = \frac{B W}{\alpha H_1} (0 \leq x / D_e < \alpha) \hspace{1cm} (8a)$$

$$K_{i2} = 0 (\alpha \leq x / D_e < 1 - \beta) \hspace{1cm} (8b)$$

$$K_{i3} = -\frac{W}{H_1} (1 - \beta \leq x / D_e) \hspace{1cm} (8c)$$
Of which: \( x \) the horizontal displacement of stigma; \( D \) is the effective width of the column cross-section, according to the principle of equal area, the circular column is equivalent to a square column \( D = \sqrt{\pi r^2} \), where \( r \) is the radius of the column; \( \alpha \) For the stigma yield displacement and the effective column width ratio, taken as 0.2 [9]; \( \beta \) For the degradation factor, taken as 0.5; \( W \) is equivalent roofing quality; \( H \) For the height of the pillars.

The bracket set style "shear bending rod" stiffness \( K \) in different stress stages (after the elastic stage and yield) size, according to the model of restoring force test [5] of four-layer bracket set work (Figure 9) and lateral stiffness formula

\[
K = \begin{cases} 
0.221 \mu N & (0 < x_i(t) \leq 4.53 \text{mm}) \\
0.033 \pi \tau A_i & (4.53 \text{mm} < x_i(t) \leq 35.32 \text{mm}) 
\end{cases}
\]

Where: The sliding friction coefficient \( \mu \) between the wood for the test, the test value is 0.33; \( N \) is the vertical load acting on each bracket set ((kN)); \( n \) is the number of; \( \tau \) For the transverse grain compressive strength (MPa), taken as 3.7MPa; \( A \) For the bread tenon stripes compression area (mm²).

![Figure 9. Bracket set resilience model](image)

In this paper, the damping ratio \( \zeta \) of the equivalent damping theory method is mainly used and the damping matrix of the ancient building is calculated by Rayleigh damping theory [C], the equation is:

\[
\zeta = \frac{\Delta E}{4\pi E} 
\]

\[
[C] = \alpha_1 [M] + \alpha_2 [K] 
\]

Where: \( \Delta E \) is the energy dissipated for the system; \( E \) is the maximum energy of the system; \( \alpha_1 \) and \( \alpha_2 \) for the proportionality coefficient, the damping ratio \( \zeta \) and the natural frequency \( \omega_i \) of the component corresponding to the i-th mode of the ancient building can be calculated by the formula (12) [10]. The natural frequencies of each mode \( \omega \) can be obtained by the white noise test.

\[
\alpha_1 = 2 \left( \frac{\zeta_i - \zeta_{i+1}}{\omega_i - \omega_{i+1}} \right) \left( \frac{1}{\omega_i^2} - \frac{1}{\omega_{i+1}^2} \right)
\]

\[
\alpha_2 = 2 \left( \zeta_i - \zeta_{i+1} \right) \left( \omega_i^2 - \omega_{i+1}^2 \right)
\]
4. ASYMMETRIC TRADITIONAL ANCIENT ARCHITECTURE STYLE PROTECTION TEST VERIFICATION

In order to verify the accuracy of the method above, combined with the shale test of the asymmetric ancient building model (Figure 10) conducted by our research group, according to the data obtained from the experiment, the protection calculation is carried out by Matlab 2010 software, and the established method is compared and verified.

Figure 10. Asymmetric village and town ancient buildings

4.1. Determination of Asymmetric Style Protection Model Parameters

The damping ratio of the ancient building mass system is obtained by the formula (10); The natural frequency is calculated from the free vibration after the hammer strikes; The dynamic friction coefficient $\mu_1$ between the column foot and the stone is 0.40, the dynamic friction coefficient $\mu_2$ between the wood is about 0.33; Equivalent lateral stiffness at different stages of force in a single-pillared "swinging column" is given by Eq. (8). Assuming that the deformation of two pylons is coordinated, the equivalent of the "swinging pillar" The anti-side stiffness can be simply superimposed according to the equivalent anti-side stiffness of two pylons; Equivalent anti-side stiffness of "shear bending bar" can be calculated according to Eq. (9). After calculation, the value of each parameter as shown in Table 1 and Table 2.

<table>
<thead>
<tr>
<th>Quality / t</th>
<th>Lateral column stiffness $K_{1i}$ / (kN mm$^{-1}$)</th>
<th>bracket set Anti-side stiffness $K_{2i}$ / (kN mm$^{-1}$)</th>
<th>Friction coefficient $\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column rack m1</td>
<td>Roof m2</td>
<td>Rise section $K_{11}$</td>
<td>Horizontal section $K_{12}$</td>
</tr>
<tr>
<td>0.20</td>
<td>3.6</td>
<td>0.12</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2. Model style parameters

<table>
<thead>
<tr>
<th>Condition</th>
<th>Natural frequency f / Hz</th>
<th>Damping ratio $\zeta$</th>
<th>Damping coefficient / (kN mm$^{-1}$ s)</th>
<th>$C_1$</th>
<th>$C_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 gal</td>
<td>2.10</td>
<td>0.030</td>
<td>0.293</td>
<td>3.564</td>
<td></td>
</tr>
<tr>
<td>200 gal</td>
<td>1.70</td>
<td>0.035</td>
<td>0.255</td>
<td>2.896</td>
<td></td>
</tr>
<tr>
<td>300 gal</td>
<td>1.65</td>
<td>0.039</td>
<td>0.305</td>
<td>3.682</td>
<td></td>
</tr>
<tr>
<td>400 gal</td>
<td>1.60</td>
<td>0.041</td>
<td>0.371</td>
<td>4.067</td>
<td></td>
</tr>
<tr>
<td>500 gal</td>
<td>1.60</td>
<td>0.043</td>
<td>0.389</td>
<td>4.328</td>
<td></td>
</tr>
<tr>
<td>600 gal</td>
<td>1.60</td>
<td>0.045</td>
<td>0.423</td>
<td>4.402</td>
<td></td>
</tr>
<tr>
<td>800 gal</td>
<td>1.50</td>
<td>0.047</td>
<td>0.390</td>
<td>4.319</td>
<td></td>
</tr>
<tr>
<td>1000 gal</td>
<td>1.70</td>
<td>0.048</td>
<td>0.533</td>
<td>4.681</td>
<td></td>
</tr>
</tbody>
</table>

4.2. Result Verification

Using equation (3), Matlab 2010 software is used to solve the two-point asymmetric model and compare it with the shaking table test results. Table 1 shows the calculated values and experimental values of the
acceleration responses of particles under different operating conditions for the two-point asymmetric ancient buildings with asymmetric structures. $\ddot{x}_{1\text{max}} (t)$ and $\ddot{x}_{2\text{max}} (t)$ is the peak acceleration response of the mass point $m_1$ and $m_2$. It can be seen from Table 2 that the acceleration response calculated by the model of protection for the ancient buildings in this paper is very close to the measured results of the shaking table test. The overall results are in good agreement with each other, indicating that the method of style protection is accurate and feasible.

5. CONCLUSIONS

This paper presents a method of Asymmetric Village and Town Ancient Architecture Style Protection Based on the Historical Feature Sequential Logic. By combining the experimental results with the theoretical derivations, the method of calculating the appearance of each parameter of the method is obtained. The main conclusions are drawn as follows:

(1) According to the force mechanism protection of asymmetrical ancient buildings under the action of horizontal earthquake, the dovetail stanchion frame can be equivalent to the "swinging pillar" in which only lateral displacement occurs, and the stave layer can be equivalent to the ideal "shear bending bar";

(2) According to the state of force in different stages of the ancient building and the relationship between countertop inertia force and the maximum static friction force between the foundation stone and the column foot, the overall equivalence between the elastic work stage and the inelastic work stage of the ancient building is given Model, and gives a detailed calculation of the parameters of the equivalent model:

The peak acceleration response of the mass particle calculated by the style protection basically agrees with the test results of the shaking table, and the error is small. It proves that the protection of asymmetrical ancient buildings presented in this paper can well reflect the seismic action of the asymmetric ancient buildings at different working conditions Under the style of protection.

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