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Analysis of Seismic Performance of Damaged Wooden Structure Column Foot

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Abstract. In order to study the dynamic response of the damaged timber frame column foot, a four-grade single-span timber frame model with damaged column foot was established to study the frequency change of the timber frame, and the acceleration trend of column top and foot under different frequencies and different peak harmonics were analyzed. The results show that the frequency range of the damaged wooden frame of the column foot is 0.8HZ-2.5HZ. With the increase of the input peak value, the shock absorption effect of the wooden frame under 100gal is obviously better than 50gal. As the elastic modulus of the damaged column foot increases, the shock absorption effect of the wooden frame gradually weakens.

1. Introduction

Chinese traditional ancient architecture is the crystallization of ancient Chinese wisdom and precious legacy left by the ancestors. The special structure of ancient Chinese buildings allows them to survive thousands of years without falling. Column feet floating on the foundation stone, tenon-and-mortise joints, bucket arch layer, large roof and other structures provide favorable conditions for the seismic resistance of the wooden structure. The column foot rests on the foundation stone. With rain erosion, biological corrosion and other reasons, the nature of the column foot will change, which will greatly change the seismic performance of the wooden structure, and the existing wooden structure column foot has experienced different degrees of damage. Studying the dynamic response of the column foot in the damaged state has positive significance for us to protect and the existing wooden structure.

Lu Peng derives the flexural bearing capacity degradation model of aging wooden beams by numerically simulating a wooden column, using the equivalent section method and combining the empirical formula of the thickness of the aged metamorphic layer in China [1]. Based on the two-dimensional radial cross-section model of rounded wooden pillars with obtuse edges, Gao Chao derives the governing equations of the wooden pillars in four different motion states, and gives the judgment conditions for different motion states [2]. Xue Jianyang et al. conducted a shaking table test on a hall-like wooden structure and found that the slip of the column foot can significantly reduce the seismic effect [3]. Through experiments, He Junxiao et al. found the change law of the rotation stiffness of the column foot and the equivalent radius of the section during the rocking process [4]. Zhang Fengliang et al. analyzed the embedded bending moment and frictional bending moment of the column foot, and obtained the formula for the lateral stiffness of the column frame, which was verified by experiments [5]. Wan Jia conducted a dynamic time history analysis of different damping ratios through software simulation, and studied the motion states of the wooden column at rest, slip, sway and slip sway through numerical simulation and theoretical analysis [6-7].

2. Construction and Geometrical Dimensions of Specimens

In this paper, the fourth-grade wood frame is selected. According to the relevant records of "Building Method" and the modern size conversion ratio, the specific dimensions of the wood structure can be obtained as shown in Table 1. Fen is ancient size.The vertical load of the upper part of the wood structure is replaced by two mass blocks. The size of the block is consistent with the size of the bucket, and the quality of the bucket arch and roof is determined by the "Preliminary Investigation of the Static Force of Damuzu". The weight of each mass is 4 tons. The related numerical simulation is realized by ABAQUS software simulation. The parts of the model are shown in Figure 1.

Table1.Dimensions of each component.

member	property	fen	size(mm)
column	diameter	36	552.96
	height	300	4608
pupaifang	length	400	6144
	width	32	491.52
	height	15	230.4
lan e	length	300	4608
	width	20	307.2
	height	30	460.8
mass	length	24	368.64
	width	24	368.64
	height	*	200

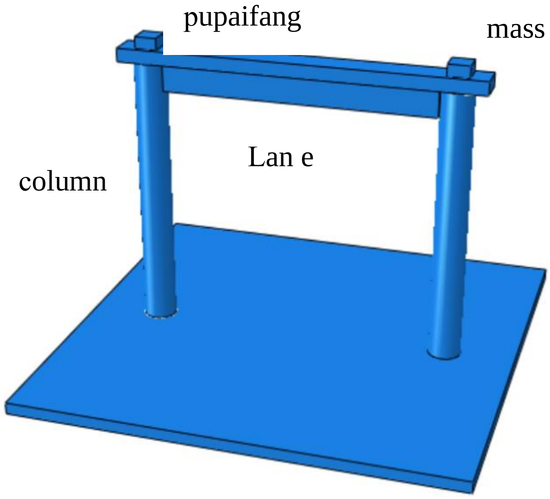

Figure 1.Wood frame model.

Wood is a special material with anisotropic material properties. The direction of wood grain is defined as along the grain direction (L), horizontal grain radial (R) and horizontal grain chord direction (T). The material properties of wood are shown in Table 2.

In order to understand the impact of column foot damage on the overall performance of the wooden structure, the film layer set at the bottom of the column, the film layer and the column are still whole, for this reason the film layer is set with different elastic moduli to simulate the condition of the column foot damage. The elastic modulus of the film layer is one-eighth, one-quarter and one-half of the elastic modulus of the column, respectively.

Table 2. Physical and mechanical indexes of Northeast Korean pine.

Elastic Modulus（N/mm2）			Poisson's ratio			Shear modulus（N/mm2）			density(N/mm2)
E_1	E_2	E_3	ν_{12}	ν_{23}	ν_{13}	G_{12}	G_{23}	G_{31}	ρ
10000	650	275	0.02	0.02	0.035	650	275	210	0.434

3. Test Results and Discussions

3.1. *Description of the simulation process*

By applying the simple harmonics of 50gal and 100gal with a frequency of 2.0HZ to the bottom plate, we can observe the dynamic performance and shock absorption effect of the wooden frame. Simple harmonic lasts for 10 seconds. Select the maximum acceleration value of the column top and column bottom from each period for comparison. Due to the large diameter of the fourth-grade material column, a simple harmonic wave of 100 gal is selected to calculate the natural frequency of the structure. The simple harmonic wave is loaded for 10s first, and then the free vibration is sustained for 5s. In order to study the influence of different thickness of the film layer on the natural frequency of wood structure, the thickness of the film layer is set to 6cm and 12cm.

3.2. The changing law of natural frequency

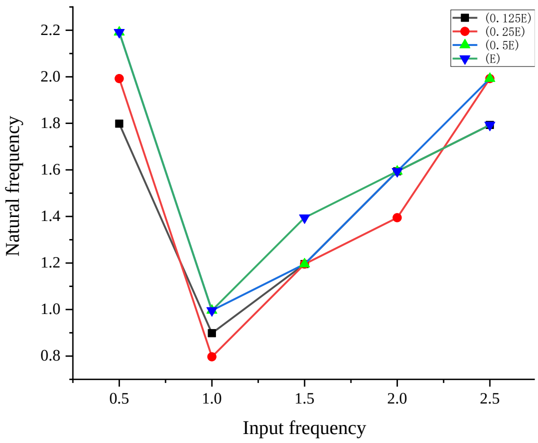

Figure 2. 6cm natural frequency .

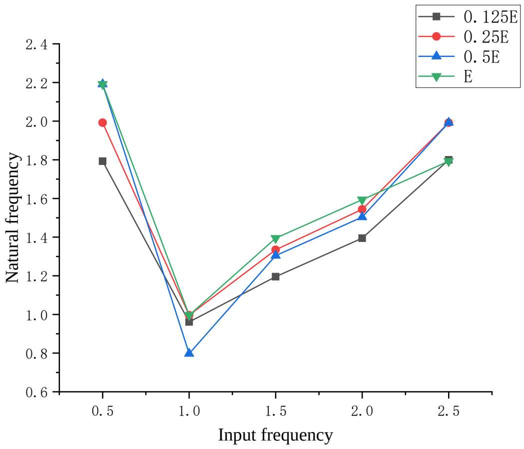

Figure 3.12cm natural frequency.

The results can be seen in Figure 2 and Figure 3. The change trend of the natural frequency of 6cm and 12cm thick film layers is similar. Because the wooden frame is placed on the foundation, when excited by the ground, the wooden structure will swing back and forth, and the lateral stiffness will change, so the frequency will also change. From 0.5HZ to 1HZ, the frequency of wood structure is decreasing, and from 1HZ to 2.5HZ, the frequency is increasing. It shows that the dynamic response is the largest at 1HZ, the relative displacement between the column bottom and the column top is the largest, and the lateral stiffness decreases the most. When the input frequency is 0.5HZ and 2.5HZ, the natural frequency of the structure is relatively large, indicating that the lateral stiffness at this time is relatively large. When the input frequency is 0.5HZ, the bottom plate vibrates slowly, which is not enough to cause violent shaking of the wooden frame. When the frequency is 2.5HZ, although the peak acceleration is 100gal, because the frequency is too fast and the peak duration is too short, the response of the wooden frame is not very sharp. Although the lateral stiffness of the wooden frame is not a fixed value, and the frequency does change, there is still a rough and most dangerous range, and determining this range is of great significance to the protection of the wooden frame. When the height of the cushion layer is 6cm, when the elastic modulus of the film layer is 0.125E, compared with the other two, the natural frequency at this time is basically the smallest, and when the elastic modulus is 0.5E, the natural frequency of the wooden frame is basically the same as the natural frequency of the complete wooden frame.

3.3. Acceleration response of the bottom and top of the column

In order to study the acceleration attenuation under different working conditions, the acceleration attenuation coefficient β_1 , β_2 , β_3 and β_4 are used for comparison. $\beta_1 = \frac{\alpha_{\text{max.top.damaged}}}{\alpha_{\text{max.top.intact}}}$,

$\beta_2 = \frac{\alpha_{\text{max.bottom.damaged}}}{\alpha_{\text{max.bottom.intact}}}$, $\beta_3 = \frac{\alpha_{\text{max.top.damaged}}}{\alpha_{\text{max.bottom.damaged}}}$, $\beta_4 = \frac{\alpha_{\text{max.top.intact}}}{\alpha_{\text{max.bottom.intact}}}$.

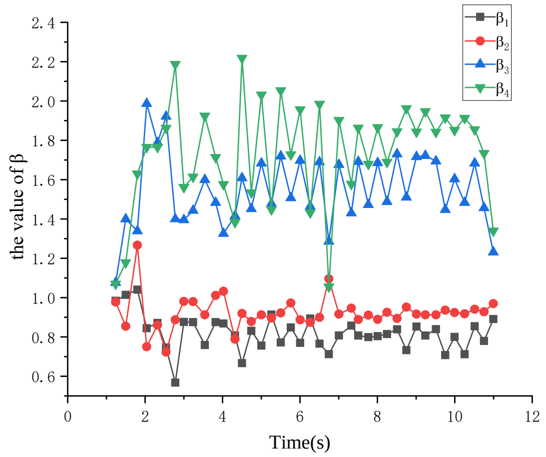

Figure 4.50gal2.0HZ(0.125E).

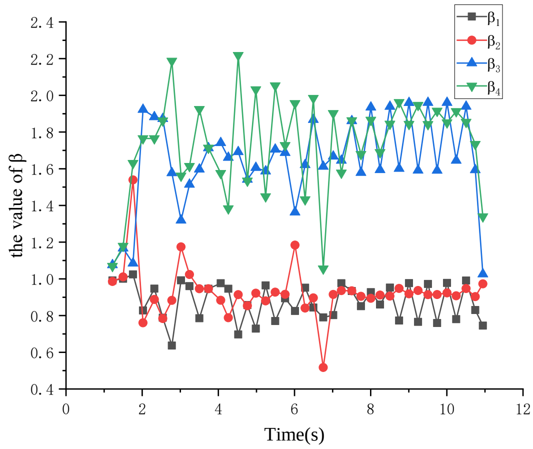

Figure 5.50gal2.0HZ(0.25E).

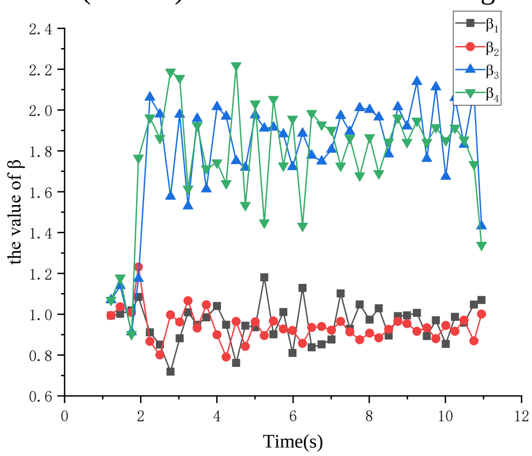

Figure 6.50gal2.0HZ(0.5E).

When the input peak value is 50gal, the results are shown in Figure 4 to Figure 6. When the modulus is reduced to the original 0.125, 0.25, 0.5, the acceleration of the column top is significantly reduced, most of β_1 is less than 1, accounting for 97.4%, 97.4%, 66.7% of the overall value, and there are 92.3%, 53.9%, 28.2% of β_1 Less than 0.8, β_2 less than 1 accounted for 92.3%, 89.7%, and 87% respectively. It can be seen that as the elastic modulus of the column bottom of the damaged timber frame increases, the seismic isolation and shock absorption effect gradually weakens. The values of β_3 and β_4 are significantly greater than β_1 and β_2, indicating that the acceleration of the top of the column has increased significantly. When the elastic modulus is 0.125 and 0.25 times of the original, β_4 is obviously larger than β_3, indicating that the acceleration amplification effect of the intact wooden frame is more obvious.

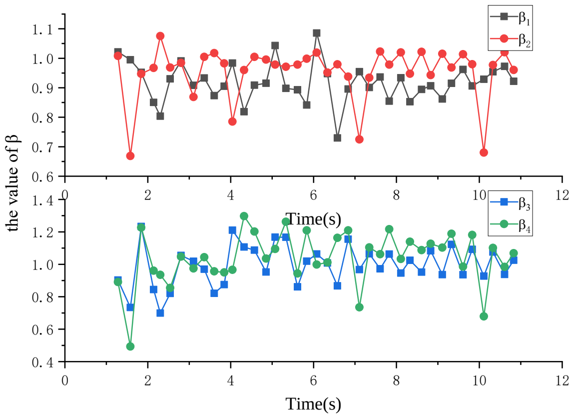

Figure 7.100gal2.0HZ(0.125E).

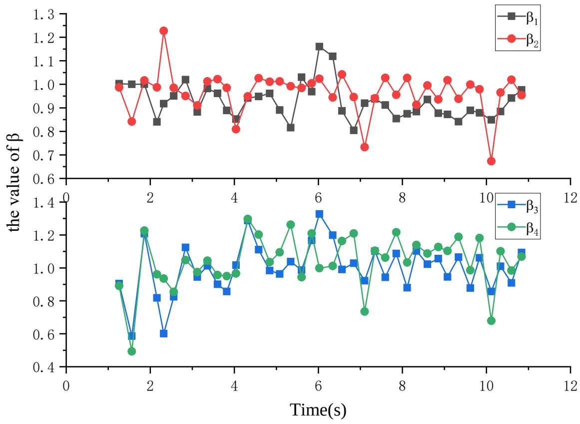

Figure 8.100gal2.0HZ(0.25E).

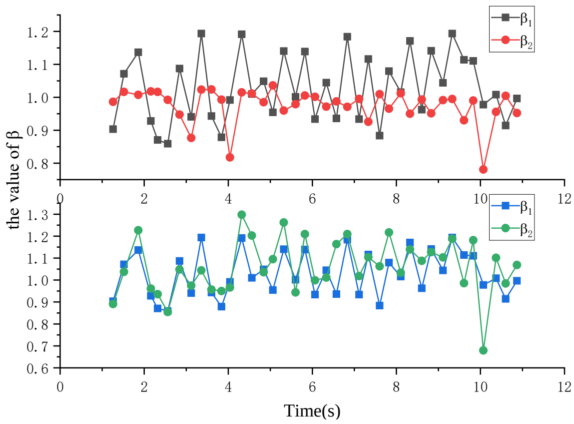

Figure 9.100gal2.0HZ(0.5E).

When 100gal is input, the results are shown in Figure 7 to Figure 9. When the elastic modulus of the damaged part is reduced to the original 0.125, 0.25, 0.5, most of β_1 is less than 1, accounting for 92.3%, 82.1%, and 43.6%. 33.3%, 46.2% and 10.2% of β_1 are less than 0.8, and β_2 less than 1 accounts for 69.2%, 64.1%, and 64.1%, respectively. The values of β_4 and β_3 are not much different from those of β_1 and β_2, which are obviously less than the working condition of 50gal. It shows that the shock absorption effect of 100gal is obviously better than 50gal. When the elastic modulus is 0.125, 0.25, and 0.5 times of the original, the β_4 less than 1 accounted for about 38.5%, 38.5%,and33.3% of the total, and the β_3 less than 1 accounted for 48.7%、48.7%and 43.6%, of the total, respectively. The shock absorption effect of the damaged wooden frame is better than that of the intact wooden frame.

4. Conclusion

(1) Regardless of how the height of the film layer changes and how the elastic modulus changes for wooden structures, the overall change trend of the natural frequency under different input frequencies is the same. When the input frequency is 1HZ, the natural frequency of the structure is the smallest.

(2) Under the 100gal working condition, β_3 and β_4 are obviously smaller than the 50gal working condition, indicating that with the increase of the input acceleration, the seismic performance of the wooden frame becomes better.

(3) Under different working conditions, when the elastic modulus of the film layer gradually increases, the proportion of β_1 less than 1 gradually decreases, indicating that the shock absorption effect of the wooden frame is gradually weakening.

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