# Study on the Factors Affecting the Dynamic Characteristics of Brick Masonry Structure Houses

Yanan Fu

School of Civil Engineering, Chongqing Three Gorges University, Wanzhou, 404100, Chongqing, China

e-mail:fuyn1667@sina.com

**Abstract.** ABAQUS has been applied to establish a three-dimensional finite element model of typical brick masonry structures, in order to study the effects of brick masonry material strength, reinforced concrete structural columns, and coupling and tie constraint methods on the dynamic characteristics of brick masonry structures. Research has shown that setting up structural columns in brick masonry buildings can reduce the structural period, and improving material strength can increase structural stiffness. The contact mode between the wall and the structural column only affects the first and second modes of the house. The research results on the influencing factors of the dynamic characteristics of brick masonry structures can provide reference for the study of various dynamic load responses of brick masonry structures in the Three Gorges Reservoir Area in China.

**Keywords:** contact mode, brick masonry structure house, dynamic properties

## 1 INTRODUCTION

In general, modal analysis is performed before other dynamic analyses. Modal analysis is the foundation of various dynamic analyses and can reflect the vibration characteristics of structures and systems, which determine the response of various other dynamic loads.

Michele B and Andrea V [1] conducted numerical analysis on the damage types and the first four modes of a historic church before and after reinforcement using ANSYS. Naida A, Mustafa H and Daniel V O [2] analyzed the first three modes of a four-story unreinforced masonry residential building using ABAQUS. Massimiliano F. et al [3] investigates the dynamic characterisation of two monumental masonry towers located in Italy using finite element model.

Zhang W X [4], Zheng N N [5], Wu T [6], Sun L [7] and others analyzed the modes of masonry structures using finite element software ABAQUS.

Using finite element software ABAQUS, the factors affecting the dynamic characteristics of brick masonry structures were studied, mainly analyzing the effects of material strength, reinforced concrete structural columns, coupling and tie constraints on the dynamic characteristics of brick masonry structures. The modal analysis in this


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study used linear perturbation analysis steps and a lanczos solver, using linear elements and linear material properties, ignoring nonlinear properties [4-7].

# 2 THE ESTABLISHMENT OF FINITE ELEMENT MODEL FOR A BRICK MASONRY STRUCTURE BUILDING

## 2.1 Simulated Object

**Table 1.** Simulated object.

| Model | WZ-1 | WZ-2 | CWZ-1 | XJ-1 | XJ-2 | CXJ-1 |
|---|---|---|---|---|---|---|
| Structural column | No column | No column | No column | Cast-in-site column | Cast-in-site column | Cast-in-site column |
| Material strength | [a]Common | [b]High strength | [a]Common | [a]Common | [b]High strength | [a]Common |
| Constraint mode | tie | tie | coupling | tie | tie | coupling |

[a] Materials with a strength of MU10 and M5
[b] Materials with a strength of MU25 and M10

To evaluate the influencing factors of the dynamic characteristics of masonry structure houses, the dynamic characteristics of masonry structures are studied from three aspects: the setting of construction columns, material strength, and the coupling and tie restraint methods. The simulation objects are shown in Table 1, with a total of 6 models. The basic mechanical properties of the materials used in the simulation object are presented in Table 2.

**Table 2.** Mechanical parameters of materials.

| Material | Density (kg $m^{-3}$) | Elastic modulus (N $mm^{-2}$) | Poisson's ratio | Average compressive strength (N $mm^{-2}$) | Average tensile strength (N $mm^{-2}$) |
|---|---|---|---|---|---|
| C20 Concrete | 2 400 | $2.55\times10^{10}$ | 0.2 | 15.79 | 1.96 |
| 1st floor masonry | 1 500 | 2 011 | 0.15 | 3.41 | 0.31 |
| 2nd floor masonry | 1 500 | 2 111 | 0.15 | 3.76 | 0.32 |
| HPB235 steel | 7 800 | $1.9\times10^{11}$ | 0.3 | — | 400 |

## 2.2 Selection of ABAQUS Model and Parameter Setting

Due to the fact that masonry is primarily subject to tensile failure, which is similar to the failure mode of concrete, both concrete and masonry are modeled using the Concrete damage plasticity model to establish the constitutive relationship between concrete and masonry [4-7]. When performing finite element analysis on masonry structures, there are separate models and monolithic models. This article focuses on modeling and analyzing the overall structure, and it is advisable to use a monolithic model for this purpose [4-7].

The elastic modulus and Poisson's ratio of concrete are determined in accordance with the "Code for Design of Concrete Structures of the People's Republic of China (GB50010-2010)". For masonry structures, HPB235 grade steel are used, with a yield strength of 235MPa and a plastic strain value of 0 at yield. The elastic modulus and Poisson's ratio of masonry are determined in accordance with the "Code for Design of Masonry Structures of the People's Republic of China (GB5003-2011)", with a Poisson's ratio of 0.15 for masonry.

### 2.3 Establishment of Finite Element Model

The framework of the longitudinal and stirrup reinforcement is established in part, the properties are assigned to the cross-section and attributes respectively, and the reinforcement is embedded into the concrete entity in interaction. This reinforcement method facilitates the inspection of reinforcement stress [4-8].

The masonry wall segments are connected to the structural columns through joint bars and tie bars, which are tightly connected, using the tie and coupling constraints [8]. This paper conducts a comparative analysis of the two, studying the impact of the wall column restraint conditions on the dynamic characteristics of the structure. The prefabricated slabs are restrained by tie constraints. To simulate the contact relationship between the sides of the prefabricated slabs and the longitudinal load-bearing walls, the surface-to-surface contact simulation in the interaction module is used. Since the walls are built with biting joints, and the walls are connected by tie constraints, the friction coefficient is set at 0.7 [5].

### 2.4 Grid Unit Division of Finite Element Model

In order to avoid abnormal vibration modes during modal analysis, at least two units are required in the thickness direction. The thickness of both the inner and outer walls of the masonry structure is 240mm, and the grid size of the units is set at 120mm. During modeling, the circular holes of the prefabricated hollow slabs are converted into square holes based on the principle of stiffness equivalence, and then the hollow slabs are converted into solid slabs with a thickness of 120mm. As a result, the thickness of the solid slabs is reduced to 80mm, so the grid size of the slabs is set at 40mm. C3D8R units are used for walls, slabs, and columns, and T3D2 units are used for reinforcement [4-8]. Stairs are not considered during modeling.

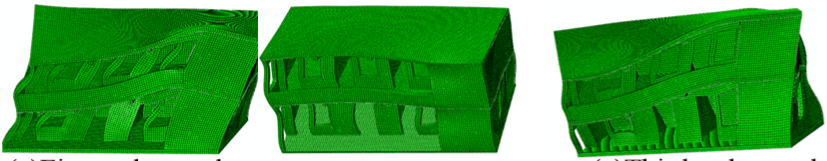
## 3 MODAL ANALYSIS OF MASONRY STRUCTURE BUILDINGS

### 3.1 Modal Analysis of WZ-1

The first eight frequencies and periods of the finite element model WZ-1 for brick masonry structure buildings are shown in Table 3, and the first three modes are shown in Figure 1. Figure 1(a) shows the first mode of the finite element model WZ-1, which mainly moves along the longitudinal direction of the building. Due to the weakened stiffness of the cantilevered balcony structure, some parts of the structure at the cantilevered balcony undergo torsional deformation. Figure 1(b) shows the second mode of the finite element model WZ-1, which mainly moves along the lateral direction of the building. Due to the weakened stiffness of the cantilevered balcony structure, some parts of the structure at the cantilevered balcony also undergo torsional deformation. Figure 1(c) shows the third mode of the finite element model WZ-1, and the overall structure undergoes severe torsional deformation. This may be due to the weakened stiffness of the local structure caused by the cantilevered balcony.

**Table 3.** The first 8 frequencies and periods of WZ-1.

| Order | 1 | 2 | 3 | 4 | 5 | 5 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Frequency | 10.18139 | 12.57862 | 12.99883 | 15.59819 | 16.53713 | 16.66111 | 16.66667 | 17.18213 |
| Period | 0.09816 | 0.0795 | 0.07693 | 0.06411 | 0.06047 | 0.06002 | 0.06 | 0.0582 |



(a)First order mode (b)Second order mode (c)Third order mode

**Fig. 1.** The first three modes of a case model (WZ-1) rural residence

**Table 4.** The first 8 orders of period of the simulation object.

| Or-der | WZ-1 | WZ-2 | CWZ-1 | XJ-1 | XJ-2 | CXJ-1 |
|---|---|---|---|---|---|---|
| 1 | 0.0982 | 0.0613 | 0.107 | 0.0868 | 0.0584 | 0.1027 |
| 2 | 0.0795 | 0.0558 | 0.1022 | 0.0657 | 0.048 | 0.0847 |
| 3 | 0.0769 | 0.0443 | 0.0987 | 0.0492 | 0.035 | 0.0699 |
| 4 | 0.06411 | 0.0329 | 0.0741 | 0.038 | 0.0294 | 0.0456 |
| 5 | 0.06047 | 0.0312 | 0.0702 | 0.0354 | 0.0282 | 0.0408 |
| 6 | 0.06002 | 0.0269 | 0.0682 | 0.0331 | 0.0246 | 0.0401 |
| 7 | 0.06 | 0.0224 | 0.0656 | 0.0262 | 0.0217 | 0.0326 |
| 8 | 0.0582 | 0.0216 | 0.0628 | 0.0259 | 0.0203 | 0.0311 |

For the basic period of masonry structures, there is an empirical formula $T1 = 0.0168\ (H0 + 1.2)$ [9], where H0 is the height of the masonry structure building. According to this empirical formula, the basic period of WZ-1 is calculated to be 0.12. Table 4 shows the first eight periods for all simulated objects. From Table 3 and Table 4, it can be seen that the natural period of the first mode of WZ-1 is 0.0982, which is different from the calculation result by 18.17%, and this error is acceptable. This may be because the cantilevered balcony of WZ-1 reduces the stiffness of the structure, thereby slightly reducing the natural period of the first mode.

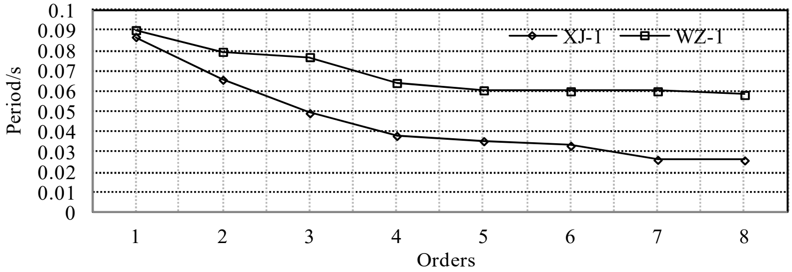



**Fig. 2.** The nature period comparison of mode XJ-1and WZ-1

### 3.2 Comparative Analysis of Inherent Periods of WZ-1 and XJ-1

Figure 2 shows the natural periods of the example models WZ-1 and XJ-1. From Figure 2, it is evident that the natural period of the finite element model XJ-1 with construction columns is significantly lower than that of the finite element model WZ-1 without construction columns.

### 3.3 Analysis of the Influence of Material Strength on Natural Period

From the comparison of the natural periods of finite element models with different material strengths for the wall in Figure 3, it is evident that material strength significantly affects the natural periods of each mode of the masonry structure, and this effect is more pronounced than that of the addition of structural columns. The primary cause may be attributed to the influence of the material's elastic modulus; as the material strength increases, so does its corresponding elastic modulus. Therefore, enhancing material strength is an effective method to increase structural stiffness, but it does not affect the house's vibration patterns. The vibration patterns of the first three modes for WZ-2 with high-strength materials are similar to those of WZ-1, as depicted in Figure 1.

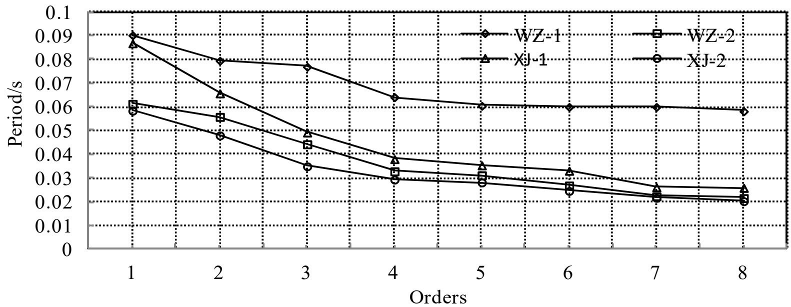



**Fig. 3.** The nature period comparison of mode XJ-1, WZ-1, XJ-2 and WZ-2

### 3.4 Analysis of the Influence of Finite Element Model Constraint Modes on Periodicity

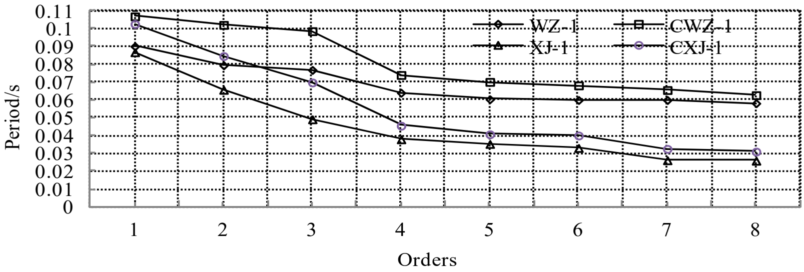



**Fig. 4.** The nature period comparison of mode XJ-1, WZ-1, CXJ-1 and CWZ-1

From the comparison of the natural periods of the finite element models with different restraint methods between the wall and the constructional column in Figure 4, it can be concluded that the restraint methods of the wall and the constructional column have a significant impact on the mode shapes of the first three modes of the finite element model of the masonry structure house. When using the coupling restraint, the first mode is lateral translation, the second mode is longitudinal translation, and the directions of the first two modes are opposite to those of the tie restraint. When using both the coupling and tie restraints, the third mode is torsion. The restraint methods have a significant impact on the periods of each mode of the masonry structure. From Table 4, it can be seen that the period difference of the first three modes between models XJ-1 and CXJ-1 is 0.0159, 0.019, and 0.0207, respectively. Therefore, the restraint methods of the finite element model have a significant impact on the period of the structure, and the stiffness of the wall and constructional column with coupling restraint is less than that with tie restraint. After increasing the strength of the wall to MU25 and M10, the period of the structure decreases compared to when the strength of the wall is MU10 and M5, indicating that the stiffness of the house with constructional columns increases with the increase of masonry strength. However, increasing the strength of the wall has less effect on stiffness than enhancing the tensile strength between the wall and constructional columns.

Therefore, if the tie between the structural column and the wall is not strong enough, and if no horse teeth or tie bars are set, it will have a significant impact on the dynamic characteristics of the masonry structure.

## 4 CONCLUSION

This article establishes a three-dimensional finite element model of a brick masonry structure house using the finite element software ABAQUS, and studies the effects of material strength, reinforced concrete constructional columns, tie, and coupling restraint methods on the dynamic characteristics of brick masonry structure houses. The results show that:

The natural period of the building structure is significantly reduced after the installation of construction columns.

The impact of material strength ratio on the natural periods of various modal shapes of masonry structures is greater than that of the setting of structural columns.

The contact method between the wall and the structural column has a significant impact on the vibration mode shape of the building.

Improving material strength is an effective method to enhance structural rigidity, but the impact of increasing material strength on rigidity is not as significant as the enhancement of the tensile bond between the structural columns and the walls.

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