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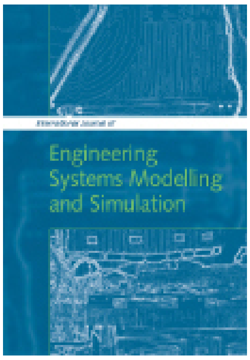

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Study on optimisation of seismic performance of special-shaped column structure in residential buildings based on BIM technology

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Abstract: In order to solve the problems of poor seismic performance of special-shaped column structure of residential buildings after traditional optimisation methods, a seismic performance optimisation method of special-shaped column structure of residential buildings based on BIM technology is proposed. Building visual information base model is constructed by BIM technology. The variation of the parameters of special-shaped column structure in residential buildings is analysed. Then, considering the economic benefits of the special-shaped structure of residential buildings, a comprehensive two-way driving structure is built. The displacement parameters of the special-shaped structure of residential buildings are obtained, and then its multi-degree of freedom system and equivalent single degree of freedom are analysed. Upon determining the displacement degree of the special-shaped column structure of residential buildings, the optimisation of the special-shaped column structure of residential buildings is completed. The results show that the maximum displacement curvature ductility coefficient is about 4.5 and variation range of energy dissipation coefficient is 0.03~0.04.

Keywords: BIM technology; residential building; non-standard pillar; Rhino parametric model; seismic performance optimisation; special-shaped column structure.

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1 Introduction

Reinforced concrete the structure of non-standard pillar in residence is a new structure in residential buildings. Compared with rectangular column, special-shaped column has particularity and complexity in seismic and structural bearing capacity (Zeng et al., 2016). The special-shaped column frame structure building has certain advantages in the wall reform, energy saving, reducing the weight of the building, increasing the use area and adapting to the functional changes. The non-standard pillar structure in residence can reduce the cost, improve the utilisation rate of indoor space, reduce the self-weight of the structure and increase the room use area. Therefore, it has been widely used in recent years (Gao et al., 2018; Ren et al., 2016). But non-standard pillar structure in residence has many connection points, so the seismic performance is not ideal (Liu et al., 2018; Zang et al., 2017). To solve this problem, researchers in related fields have done a lot of research.

In Xu and Hu (2018), an optimisation method for non-standard pillar in residence is proposed based on particle swarm optimisation algorithm. The method takes the engineering cost and seismic performance as the optimisation objectives, and introduces multi-subgroup co evolution mechanism to carry out the seismic optimisation design of the structure of non-standard pillar in residence. Through elite learning strategy and external files, the particle swarm optimisation algorithm is improved, and the improved particle swarm optimisation algorithm is used to optimise the ability of non-standard residential pillars to withstand earthquakes. However, the method can not effectively analyse ability of non-standard residential pillars to withstand earthquakes. And the displacement ductility coefficient of the optimised the structure of non-standard pillar in residence is low. In Xue et al. (2017), the ability of non-standard residential pillars to withstand earthquakes. based on 3D-6-DoF simulation is proposed. The ability of non-standard residential pillars to withstand earthquakes. Under seismic wave input test is simulated by 3D-6-DoF simulation. The dynamic characteristics such as damping ratio, vibration mode and natural frequency of the structure of non-standard pillar in residence model are scanned by white noise, and the ability of non-standard residential pillars to withstand earthquakes of residential building is optimised according to the dynamic characteristics. However, due to the interference of noise, the energy dissipation coefficient of the structure of non-standard pillar in residence is low, and the application performance of the method is not ideal. In Rong et al. (2017), an optimisation method for ability of non-standard residential pillars to withstand earthquakes. Based on low-cycle repetitive loading test is proposed. The method performs low-cycle repetitive loading test on special-shaped column structural specimens with different reinforcement strength, volume stirrup ratio and axial compression ratio, and optimises the ability of non-standard residential pillars to withstand earthquakes according to the test results. The research object of this method is wide, and there are many types of the structure of non-standard pillar in residence, but this method can not control the axial compression ratio in a reasonable range, and there is a problem of poor application.

To solve the above problems, a new optimisation method for the structure of non-standard pillar in residence buildings is proposed. In this method, Rhino parametric model is used to realise the design of comprehensive bidirectional driving architecture, and BIM technology is used to construct a visual information database model to complete the reorganisation of structural information of special-shaped columns, and to obtain the statistical eigenvalues of three-dimensional feature extraction. According to the gravity load effect and horizontal seismic action effect of the composite the structure of non-standard pillar in residence, the non-standard pillar structure in residence in residential buildings is realised through the corresponding structural measures. The experimental results show that the proposed method is more applicable in displacement ductility coefficient, energy dissipation coefficient and axial compression ratio. The technical route of this paper is as follows

1 This paper analyses the working principle of BIM technology, and applies it to the structural optimisation of special-shaped columns in residential buildings.

2 According to the visual information base model constructed by BIM technology, the parameter changes of the structure of non-standard pillar in residence are analysed. At the same time, the economic benefits of special-shaped structure of residential building are considered, and the comprehensive bidirectional driving structure is constructed.

3 On the basis of the above analysis, the displacement parameters of the special-shaped structure of residential buildings are obtained, and the unconstrained free system and unconstrained and free system with the same function are analysed, so as to determine the displacement degree of non-standard pillar structure in residence, and complete the optimisation of non-standard pillar structure in residence.

4 Experimental analysis.

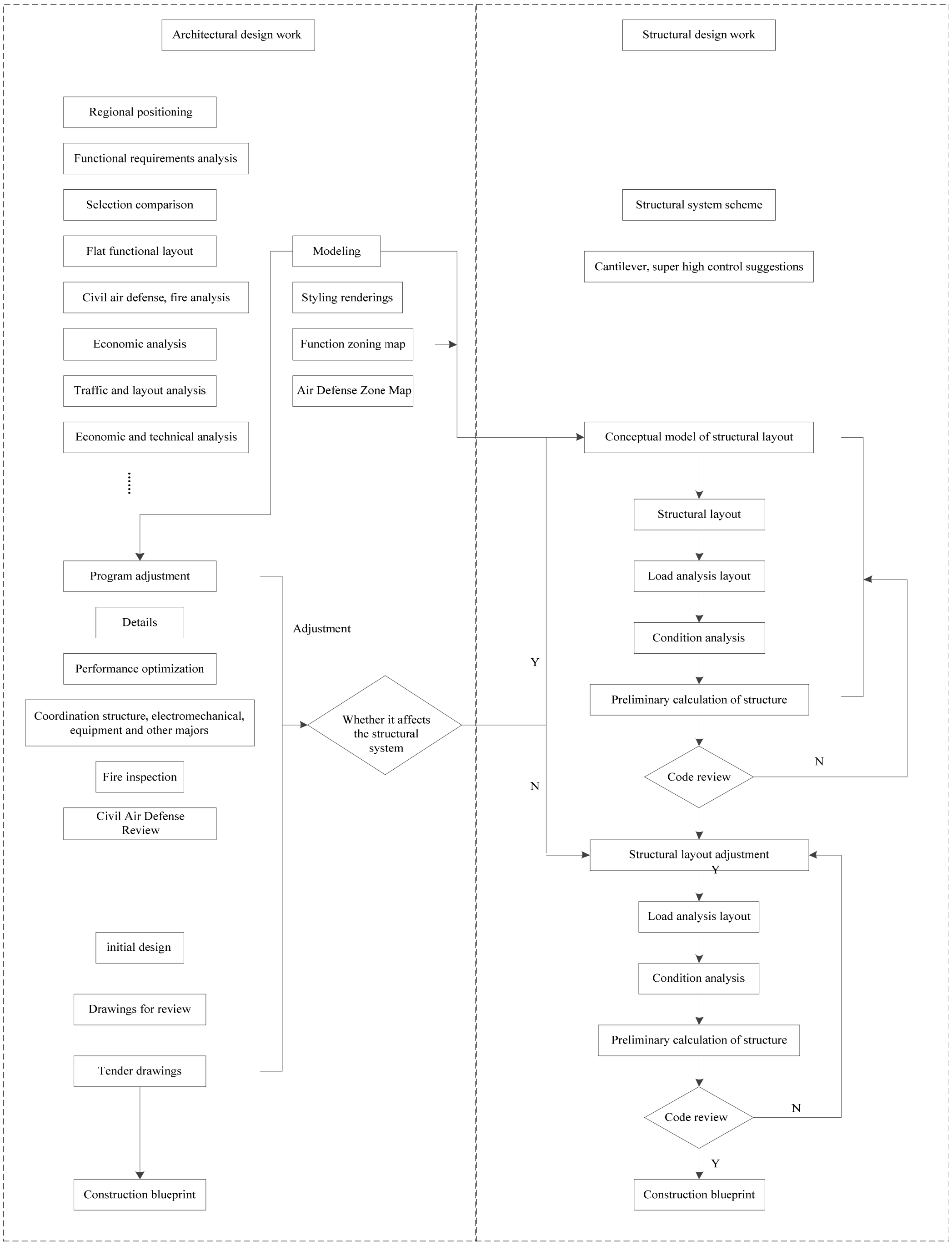
5 Conclusion and future prospects.

2 BIM visual information base model and integrated bidirectional driving architecture

2.1 Working principle of BIM technology

BIM is a kind of building information model, which can be used in engineering design and construction management. It is based on three-dimensional graphics, guided by building objects, and designed by computer. BIM technology was proposed by American Autodesk Company in 2002. BIM technology effectively solves the problem of building information dispersion and helps buildings gather information. Construction to the end of the project, all the information will be collected in a three-dimensional model information database for the convenience of relevant personnel. In recent years, BIM technology has been promoted in various fields. The application framework of BIM technology is shown in Figure 1.

Figure 1 Application framework of BIM technology



2.2 *Visual information base model of BIM building*

For to optimise the ability of non-standard residential pillars to withstand earthquakes. of residential buildings, it is necessary to construct the building visual information base model by BIM technology. According to the visual information database model, the parameter changes of non-standard pillar structure in residence in residential buildings are analysed, so as to improve the ability of non-standard residential pillars to withstand earthquakes of residential buildings.

Firstly, the automatic acquisition model of building 3D feature parameters is constructed, and the fuzzy clustering centre of the i^{th} type of building's three-dimensional features is obtained as follows:

$$V_i = \{V_{i1}, V_{i2}, \ldots, V_{ip}\} \tag{1}$$

In the formula, V_i represents the fuzzy clustering centre set of the i^{th} type of building's three-dimensional features, and V_{i1}, V_{i2}, …, V_{ip} represents the elements in the fuzzy clustering centre set respectively.

On the basis of the automatic acquisition model of 3D feature parameters, the BIM data structure of residential building association knowledge base is reconstructed, and the associated feature quantity of BIM data information base is obtained. That is

$$y^k = \left[y_1^k, y_2^k \ldots, y_n^k\right] \tag{2}$$

where y^k represents the set of correlation features and $y_1^k, y_2^k, \ldots, y_n^k$ represents the factor of correlation features.

Assuming $s_i^{(k)}$ is the statistical eigenvalue of building's 3D feature extraction, then the orthogonal distribution basis vector of building's 3D feature model can be expressed as follows:

$$s_i{}^{(k)} = \left[s_1^{(k)}, s_2^{(k)}, \ldots, s_n^{(k)}\right] \tag{3}$$

The three-dimensional feature information of various buildings is processed by fuzzy clustering. The fuzzy C-means clustering method is used for BIM information fusion clustering. For the sampled building 3D $A = \{a_1, a_2, \ldots, a_N\}$, when it satisfies $a_1 < a_2 < \ldots < a_N$. The spatial distribution set X of 3D BIM information fusion clustering is divided into c class. The visual information function $f(t)$ of 3D visualisation is Input. The cross distribution items of three-dimensional visual monitoring of buildings are passed through $A_i \cap A_j = \Omega$, so that the BIM information base model of 3D visualisation information reconstruction is obtained as follows:

$$H_i(x) = \sum_{K=1}^{K} p_k \ln \frac{1}{p_k} \tag{4}$$

In BIM information base, 3D information reconstruction and feature fusion clustering are carried out to improve the management ability of 3D visualisation information.

2.3 Design of comprehensive bidirectional drive architecture based on Rhino parametric model

When considering the structure of non-standard pillar in residence, the consideration of cost-effectiveness is also very important. In order to achieve the optimal seismic the ability of a building to resist the outside world, the traditional methods increase the cost budget of buildings. In order to avoid this problem, this paper uses rhino parametric model to build a heterogeneous comprehensive bidirectional drive architecture (Zhao et al., 2017; Chen et al., 2018). On the basis, the parametric three-dimensional model (Xue et al., 2017; Zhao et al., 2019), combined with economic indicators and comprehensive bidirectional driving structure, is used to obtain the coupling results of economy and seismic performance, and realise the reasonable optimisation of seismic performance of the structure of non-standard pillar in residence. In the analysis of seismic performance of the structure of non-standard pillar in residence buildings, it is necessary to accurately simulate non-standard pillar in residence through reinforcement information and later drawing (Zhu and Gao, 2016; Chen et al., 2017). In order to accurately analyse the calculation data of non-standard pillar in residence, it is necessary to update the actual drawing data and feed back the reinforcement situation of residential buildings. The development program is used to input the drawing reinforcement adjustment information into the calculation model, and the model is output through Rhino 3D model. The Rhino parametric model is shown in Figure 2.

Figure 2 Rhino parametric model

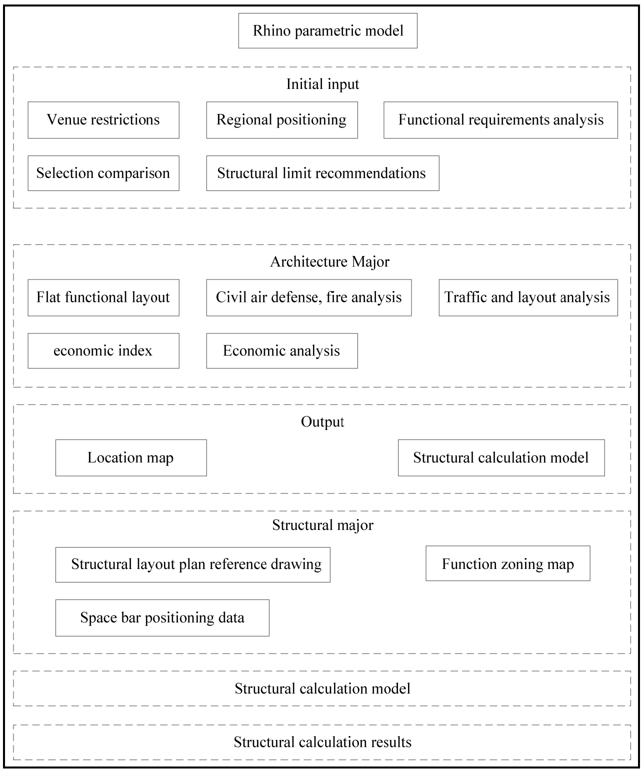
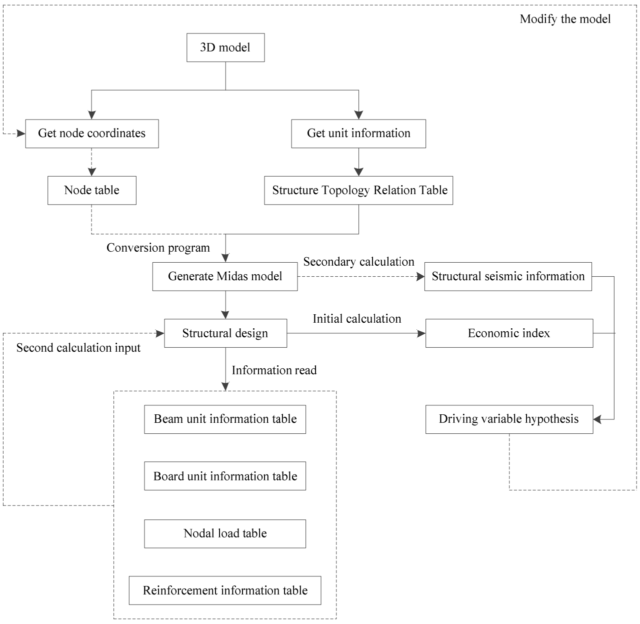


Figure 3 Integrated bidirectional drive architecture



In Figure 2, the model is used as the logic program to drive the data of building board unit, linear unit and node. On the basis of the above Rhino parametric model, a comprehensive bidirectional driving architecture combining economic indicators and seismic performance is constructed

(Ban et al., 2018; Zhang et al., 2019). The architecture is shown in Figure 3.

Through the establishment of the comprehensive bidirectional drive structure, the ability of non-standard residential pillars to withstand earthquakes of residential buildings can be optimised, and the economic benefits can also be balanced and guaranteed, which can effectively provide a reliable basis for the follow-up research.

3 Optimisation of the structure of non-standard pillar in residence based on BIM technology

3.1 Acquisition of displacement parameters of special-shaped columns in residential buildings

On the basis of BIM information base model, the displacement of heterogeneous structure of residential building is analysed in detail, so as to optimise the non-standard pillar in residence.

The non-standard pillar structure in residence includes the component interface size, floor height and column grid. According to the requirements of residential residents, the limit value of displacement angle $[\theta]$ of inter story and fortification target are determined under certain earthquake intensity (Jin et al., 2017; Liu et al., 2019).

Let $(\Delta u)_i$ represents the relative lateral displacement of each floor; u_t represents the corresponding vertex lateral displacement of the structure of non-standard pillar in residence; u_i represents the absolute lateral displacement at each floor, i.e., there is (Cai and Wan, 2018):

$$(\Delta u)_i = [\theta] h_i \tag{5}$$

$$u_t = \sum_{j=1}^{n} (\Delta u)_i \tag{6}$$

$$u_i = \sum_{j=1}^{i} (\Delta u)_j \tag{7}$$

Assuming that the displacement parameter of the structure of non-standard pillar in residence is ζ, the calculation formula is as follows:

$$\zeta = \frac{z}{H} \tag{8}$$

where H is the story height of special-shaped column in residential building, and z is the value of inter story displacement.

The absolute lateral displacement of each floor is u_i and displacement parameter ζ are brought into the following formula to obtain the corresponding vertex lateral displacement u_t of non-standard pillar structure in residence as:

$$u_t = \frac{2u_i}{3\zeta - \zeta^3} \tag{9}$$

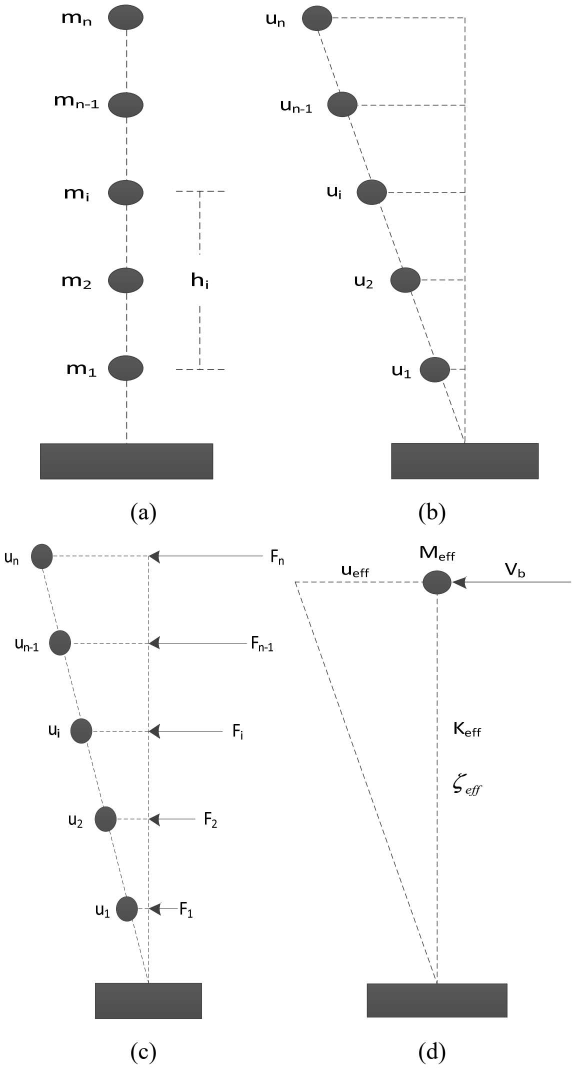
On the basis of the above analysis, the corresponding lateral displacement u_i at each floor of the residential building can be obtained as:

$$u_i = \frac{1}{2\left(3\xi - \xi^3\right)} u_t \tag{10}$$

3.2 Optimisation of displacement parameters of special-shaped columns in residential buildings

After obtaining the displacement value of the structure of non-standard pillar in residence, it is necessary to analyse its multi-degree of freedom system and equivalent single degree of freedom to determine the displacement degree of the structure of non-standard pillar in residence. Based on this, the degree of freedom of the structure of non-standard pillar in residence is optimised to determine the degree of freedom. The displacement changes of MDOF system and equivalent SDOF system are shown in Figure 4.

Figure 4 Unconstrained free system and unconstrained and free system with the same function, (a) multi-degree of freedom system (b) displacement shape (c) acceleration and inertial force (d) free system with the same function



(a) (b)

(c) (d)

Figure 4 shows the displacement changes of unconstrained free system and unconstrained and free system with the same function, and calculates the gravity load effect of the structure of non-standard pillar in residence of residential building and the equivalent stiffness corresponding to equivalent single degree of freedom system, to obtain the internal force value of the structure of non-standard pillar in residence in residential building through combination, and optimise the seismic performance of the structure of non-standard pillar in residence of residential building according to the trend and degree of displacement change.

Suppose u_{eff} represents the equivalent displacement corresponding to a system of single degree of freedom values of the same function, then the gravity load effect can be obtained as follows

$$u_{eff}=\frac{\sum_{i=1}^{m} m_i u_i^2}{\sum_{i=1}^{m} m_i u_i} \tag{11}$$

where m_i represents the lateral displacement shape function of the cantilever column.

Let M_{eff} represent the equivalent mass, and its calculation formula is as follows:

$$M_{eff}=\frac{\left(\sum_{i=1}^{n} m_i u_i\right)}{u_{eff}} \tag{12}$$

In the figure, ζ_{eff} represents the equivalent damping ratio corresponding to non-standard pillar structure in residence. The calculation formula follows:

$$\zeta_{eff}=\zeta_0+0.2\left(1-\frac{1}{\sqrt{\mu}}\right) \tag{13}$$

where ζ_0 represents the viscous damping ratio existing in the elastic stage; μ represents the displacement ductility value.

Suppose T_{eff} represents the equivalent period corresponding to a system of single degree of freedom values of the same function. Through moving distance of the same position u_{eff}, equivalent damping ratio ζ_{eff} and seismic fortification level calculation (Lu et al., 2016; Xue et al., 2017), the displacement of the optimised structure is as follows:

$$T=2\pi\sqrt{\frac{S_d}{\eta_2\alpha_{\max}g}}\left(0.1\,s\le T\le T_g\right) \tag{14}$$

$$T^2\left[0.2^r\eta_2-\eta_1\left(T-5T_g\right)\right]=\frac{4\pi^2 S_d}{\alpha_{\max}g}\left(5\,T_g\le T\le 6.0\,s\right) \tag{15}$$

where S_d represents the displacement response spectrum; $\alpha_{\max}$ represents the maximum horizontal seismic influence coefficient.

Let K_{eff} represent the equivalent stiffness corresponding to a system of single degree of freedom values of the same function. The calculation formula is as follows:

$$K_{eff}=\left(\frac{2\pi}{T_{eff}}\right)^2 \tag{16}$$

Suppose V_b is the most suitable stress to the bottom of non-standard pillar structure in residence, which can be calculated by equivalent stiffness and equivalent displacement (Gong et al., 2019; Zhang et al., 2016; Yang and Xu, 2017; Fu et al., 2017):

$$V_b=K_{eff}\times \tag{17}$$

Let F_i represent the horizontal seismic action corresponding to each particle and the expression is

$$F_i=\frac{m_i u_i}{\sum_{j=1}^{n} m_j u_j}V_b \tag{18}$$

Through obtaining the displacement parameters of non-standard pillar structure in residence in residential buildings, the multi-degree of freedom system and equivalent single degree of freedom system are analysed to determine the displacement degree of non-standard pillar structure in residence in the residential building, obtain the gravity load effect of non-standard pillar structure in residence of the residential building and the equivalent stiffness corresponding to a system of single degree of freedom values of the same function, so as to optimise the ability of non-standard residential pillars to withstand earthquakes of the residential building.

4 Experimental analysis

4.1 Experimental environment

The feasibility of BIM-based optimisation method for non-standard pillar structure is analysed by simulation experiment. The application performance of the proposed method is tested by using the traditional method as a comparative method. This test is completed in TTE network platform developed by Visual C++. The experiment uses Windows XP system, which runs memory of 4 GB. SPSS 7.0 is used to analyse the data.

4.2 Experimental parameters

The experimental parameters are shown in Table 1.

Table 1 Experimental parameters

Parameter	*Value*
Dimension of special-shaped column components in residential buildings/mm	50 × 65 × 25
Section size/mm	20 × 25
Strength of special shaped column in residential building/MPa	60~90
Maximum bearing capacity of non-standard pillar structure of building residence/kPa	100
Special shaped column reinforcement	6
Stability coefficient	0.7~0.9

4.3 Experimental indexes

The displacement ductility coefficient, energy dissipation coefficient and axial compression ratio are used as test indexes. The seismic performance optimisation method of the structure of non-standard pillar in residence in residential buildings based on BIM technology (the proposed method), the seismic performance optimisation method of non-standard pillar structure of building residence based on particle swarm optimisation algorithm [method of Xu and Hu (2018)], and ability to withstand earthquakes optimisation method of non-standard pillar structure of building residence based on three-dimensional six degree of freedom simulation [method of Xu and Hu (2018) and Xue et al. (2017)] and the seismic performance optimisation method of the structure of non-standard pillar in residence based on low-cycle reciprocating loading test [method in Rong et al. (2017)].

1. *Curvature ductility coefficient:* The value of the μ_u bending extension of the column without marking in the building refers to the comparison between the maximum bending degree and the bending angle. The curvature ductility coefficient represents the ductility of a section, while the displacement ductility coefficient and rotation ductility coefficient reflect the macroscopic ductility response of the member, which is closely related to the length of the member. The larger the ductility coefficient is, the larger the plastic deformation of the structure under strong earthquake without collapse is, which can reduce the seismic effect. Displacement ductility coefficient μ_u is calculated as follows:

$$\mu_u = \frac{\Delta_u}{\Delta_y} \tag{19}$$

   where Δ_u describes the displacement corresponding to non-standard pillar structure in residence of residential buildings; Δ_y describes the displacement of the structure of non-standard pillar in residence under yield load.

2. *Energy dissipation coefficient:* The size of the required energy value refers to an object, its energy will not be absolutely unchanged, because there is always more or less energy exchange with the outside world, the energy exchange generated at this time is energy dissipation. The higher the size of the required energy value of the building is, the stronger the energy dissipation capacity of non-standard pillar structure in residence of residential building is, which can effectively improve the ductility of the structure of building residence without pillar.

3. *The position compression ratio of the axis without column in the building residence is:* Refers to the improved axial compression ratio of the column not marked the building structural, truncation range and standard value of non-standard props axial compressive strength of the concrete. It reflects the compression of column structure. The limit of the position compression ratio of the axis without column in the building residence is mainly to control it is extensibility for the structure. The code has corresponding limit value requirements for wall limb and column. The axial compression ratio n can be calculated by the following formula:

$$n = \frac{N}{f_c A} \tag{20}$$

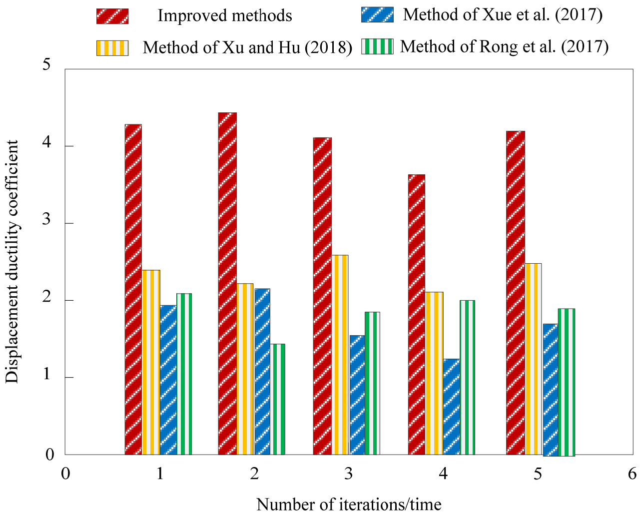
   where A represents the cross-sectional area of an unmarked column in a building; f_c can be expressed as the value of resisting pressure at the axial position of building concrete column N represents the design value of axial pressure corresponding to the structure without pillar in building residence. If the axial compression ratio is controlled below 0.10, it can ensure that the structure without pillar in building residence has sufficient ductility. The better the ductility is, the better the ability of non-standard residential pillars to withstand earthquakes is.

4.4 Result analysis

4.4.1 Ductility curvature analysis

Curvature ductility coefficient is a good test index, which can well show the structural performance of non-standard columns in residential buildings. Therefore, the improved method in this paper is compared with other three common traditional methods, and the analysis results are shown in Figure 5.

Figure 5 Comparison of curvature ductility coefficient of four methods (see online version for colours)

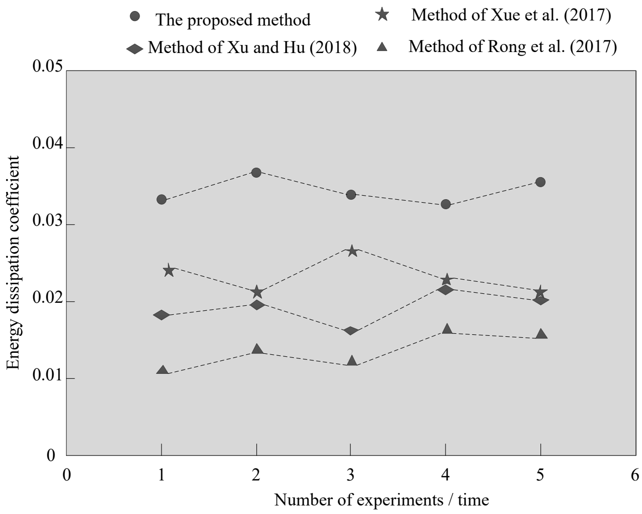


As can be seen from Figure 5 of the experimental results that the displacement ductility coefficient obtained by the proposed method in multiple iterations is higher than that obtained by the other three traditional methods, the maximum displacement ductility coefficient of the other three methods is about 2.5, 2.2 and 2.1 respectively. In contrast, the displacement ductility coefficient of special-shaped columns in residential buildings optimised by the proposed method is larger, which is because the displacement parameters of special-shaped columns in residential buildings are extracted and optimised before optimisation, which improves the displacement ductility coefficient of the structure of non-standard pillar in residence.

4.4.2 *Comparison of energy dissipation coefficients of different methods*

In order to prove that the improved method can effectively enhance the ability to resist earthquake disasters, the method of experimental analysis is used to verify. This paper mainly analyses the energy requirements of this method and the other three traditional methods.

Figure 6 Comparison of energy coefficients needed by four methods

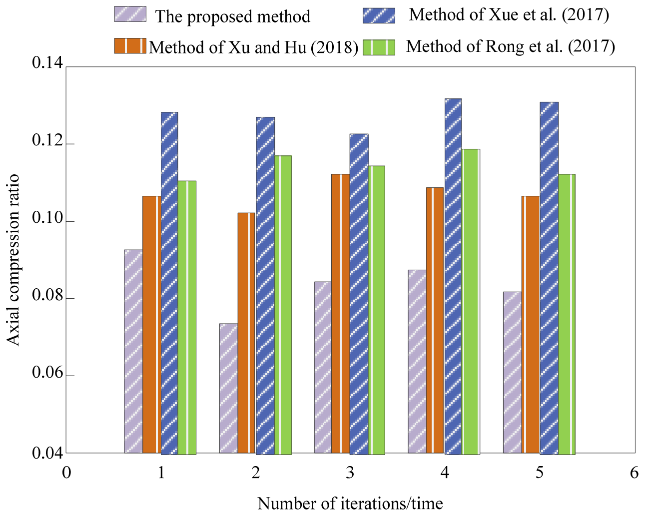


In Figure 6, analysing the experimental results that the energy coefficients needed obtained by the research method of this paper in multiple iterations is in the range of [0.03–0.04]; the energy dissipation coefficient obtained by the method in Xu and Hu (2018) fluctuates around 0.02 in multiple iterations; the energy dissipation coefficient obtained by the method in Xue et al. (2017) is in the range of [0.02–0.03]. The energy dissipation coefficient obtained by the method in Rong et al. (2017) is in the range of [0.0–0.04, 1 and 0.02]. The research conclusions of the research methods in this paper and the methods in Xu and Hu (2018), Xue et al. (2017) and Rong et al. (2017) are analysed, we can see that the energy dissipation coefficient of the proposed method is the highest, which indicates that the ductility of this article improves the non-standard residential pillar more better, because the method updates and feeds back the reinforcement situation according to the actual drawing data and direct drawing through BIM technology, which improves the energy required coefficient of the architecture of non-standard pillars in architecture.

4.4.3 *Comparison of axial compression ratio of different methods*

The method presented in this paper is quite correct. This paper chooses to analyse the pressure ratio of building axes, mainly by analysing the method presented in this paper and the pressure ratio of building axes in Xu and Hu (2018), Xue et al. (2017) and Rong et al. (2017).

Figure 7 Axial compression ratio of different methods (see online version for colours)



According to the analysis of the data in Figure 7, the axial compression ratios obtained by the proposed method in the experimental process are all below 0.10; the axial compression ratios obtained by the method in Xu and Hu (2018) are slightly higher than 0.10; the axial compression ratios obtained by the method in Xue et al. (2017) are all higher than 0.12; the axial compression ratios obtained by the method in Rong et al. (2017) fluctuate within 0.10–0.12. In the analysis the building shaft pressure ratio is less than 0.10, the ductility and ability of non-standard residential pillars to withstand earthquakes of residential buildings are better than 0.10. Through the above analysis, it can be seen that the ability of non-standard residential pillars to withstand earthquakes of residential buildings optimised by the proposed method is better, because the method uses the displacement-based seismic design method to optimise the seismic performance of the structure of a non-standard residential pillar, which improves the axial compression ratio of a the structure of a non-standard residential pillar and the seismic performance of the method.

5 Conclusions

Based on BIM technology, this paper presents an optimisation method for the structure of non-standard residential pillar to withstand earthquake disasters. Based on the analysis of BIM technology, the visual information database model is constructed to solve the parameter changes of the structure of a non-standard residential pillar. Considering the economic benefits of the structure of a non-standard residential pillar, a comprehensive bidirectional driving structure is constructed, and the displacement of the structure of a non-standard residential pillar is obtained. In order to determine the displacement degree of the structure of a non-standard residential pillar, the multi-degree of freedom system and the equivalent single degree of freedom are analysed to complete the optimisation of the structure of a non-standard residential pillar. Compared to previous solutions, the proposed method has the following advantages:

1. The maximum displacement curvature ductility coefficient of the structure of a non-standard residential pillar is about 4.5, which verifies the effectiveness of the proposed method.
2. In the results obtained after experimental analysis that the energy dissipation coefficient of the structure of a non-standard residential pillar varies from 0.03 to 0.04.
3. The axial compression ratio of the structure of a non-standard residential pillar optimised by the proposed method is always lower than 0.10.

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