Finite Element Analysis of Externally Attached Prefabricated RC Wall Panels for Reinforcement of Existing Regular Masonry Structures

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Abstract. Aiming at the characteristics of existing regular masonry structures dominated by the first vibration mode deformation, a two-dimensional practical simplified calculation method for seismic strengthening using prefabricated RC wall panels is given by the continuum approach. In this paper, the masonry reinforced with prefabricated RC wall panels is analysed using finite element analysis to demonstrate the effectiveness and applicability of this method. Combining the existing relevant experimental data and previous research results, this paper gives the performance-based design objectives and corresponding standards for existing regular masonry structures. This paper provides a simple and practical calculation and analysis method for the seismic strengthening design of existing regular masonry structures, which are widely used in China.

Keywords: Existing regular masonry structures, precast RC wall panels, seismic reinforcement.

1 Introduction

China has a large stock of existing buildings, especially those built in the 1970s and 1980s, the vast majority of which are masonry structures. The masonry structure itself is weak in compressive capacity as well as tensile strength.. And many existing masonry structures are not equipped with structural columns and ring beams. At present, these old existing buildings face many problems: the use of functions that do not meet the requirements of modern people, insufficient safety and durability, weak seismic and disaster prevention, ageing equipment settings, poor living environment and comfort. One of the key technical problems facing the renovation of existing old residential areas is that: current seismic strengthening techniques, which are mainly aimed at component load-bearing capacity and integral joint construction, involve a wide range of reinforcement, making the use of existing buildings interrupted, with a large amount of household work, making it necessary for occupants to move out and other problems.

Since 1990s, Ingham J M [1], Rosenboom O A [2] conducted a lot of research on the performance of prestressed reinforced masonry structures, the results of which

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showed that prestressing tendons reinforcement of masonry walls is a cost-effective and practical method of reinforcement.Wight G D[3] et al. conducted experimental studies on shaking table, and Liu Hang carried out experimental studies on proposed movement and proposed static [4], the above The results of the studies show that the installation of prestressing tendons can significantly improve the shear and crack resistance of existing masonry. In addition to the use of prestressing tendons to strengthen masonry walls, the use of high-performance concrete to strengthen the face is also a way of seismic strengthening of existing masonry structures. The study by Li Dan et al [5] showed that the compressive and seismic load bearing capacity of existing masonry structures can be significantly improved by using ultra-high performance concrete reinforced facing. Chen reproduced [6], ELMALYH S [7] and others carried out finite element numerical simulations of brick masonry reinforced with combined materials, and the tests proved that the brick masonry reinforced with combined materials can effectively improve its seismic capacity. Hong Anyu [8], Wang Xiaoting[9], GE[10], etc. carried out research and analysis on jacket type reinforcement of existing masonry structure, and the results showed that the lateral stiffness of the reinforced structure was significantly improved, which can effectively improve the seismic performance of the original structure.

Most of the previous research results are wet work construction, long construction period and low environmental protection. This paper proposes the reinforcement of existing masonry structures with prefabricated RC wall panels, which can greatly reduce on-site wet work construction, energy saving and emission reduction. Combined with the functional retrofitting of existing buildings and with reference to previous research results, this paper proposes a seismic calculation method for the reinforcement of existing masonry structures with prefabricated RC wall panels on the exterior walls of buildings, with a view to providing theoretical support for the seismic reinforcement of existing masonry structures.

2 Finite Element Analysis of Seismic Performance Levels of Existing Regular Masonry Structures

2.1 Determination of equivalent diagonal brace model

The equivalent diagonal brace model was originally proposed by Polyakov[11] based on tests of infill wall frame structures.Polyakov[11] considered that the infill wall in a frame under lateral horizontal forces acts as a diagonal brace that is only subjected to pressure, and therefore proposed the concept of an equivalent diagonal brace model. Under the reciprocating action of ground vibration, a single diagonal diagonal brace does not adequately describe the interaction between the walls and frames, so the single diagonal brace model is transformed into a double diagonal diagonal brace model as shown in Fig. 1. Yan Weiming[12] and others used the finite element software OpenSEES to establish a masonry model and proposed a method for calculating the width of diagonal braces applicable to masonry structures, which verified the accuracy and practicality of the diagonal brace model.

In the following, masonry walls are treated as equivalent diagonal bracing according to the results of the relevant literature, and for masonry walls without openings the width of the single diagonal diagonal bracing model for walls without openings is determined according to the following equation (1) according to the research of Holmes [13] and Saneinejad [14], etc.

$$\begin{cases} w = 0.175(\lambda H)^{-0.4}\sqrt{H^2 + L^2} \\ \lambda = \left(\dfrac{E_w t_w \sin 2\theta}{4E_c I_c H_{in}}\right)^{\frac{1}{4}} \end{cases} \tag{1}$$

In equation (1): w denotes the width of the diagonal brace, λ denotes the relative stiffness, H denotes the floor height, L denotes the span, Ew denotes the modulus of elasticity of the masonry wall, tw denotes the thickness of the masonry wall, θ denotes the angle between the diagonal brace and the horizontal plane, Ec denotes the modulus of elasticity of the concrete material of the outer frame, Ic denotes the moment of inertia of the frame column in the direction of the orthogonal loads, and Hin denotes the net height of the masonry wall except for the frame rim beam. Considering the reciprocal action of the horizontal seismic action, the width of the equivalent diagonal bracing is then divided by 2 and treated in the form shown in Figure 1.

For open-cell masonry walls, the conversion is treated according to the literature [13]. Since only the compressive effect of the equivalent diagonal bracing of the masonry wall is considered, without considering its tensile effect, the multiple encounter seismic action can be simulated by using the seam unit in a programme such as SAP2000. As shown in Fig. 2, the lateral stiffness of the one-way equivalent diagonal brace is shown in equation (2):

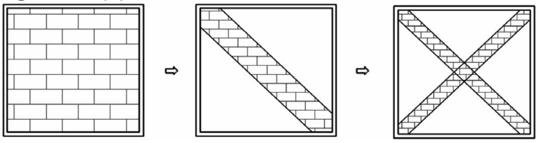

Fig. 1. Equivalent diagonal bracing of masonry wall

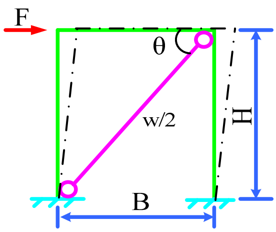

Fig. 2. Lateral stiffness of equivalent diagonal brace

$$C_{m1} = \frac{w}{2} t_w E_w \cos^2\theta \sin\theta \tag{2}$$

2.2 Elastic-plastic calculation method for diagonal diagonal brace

The equivalent diagonal bracing model is used to simulate existing masonry walls under rare earthquakes and it is necessary to determine whether the damage to the existing masonry wall is controlled by the bond strength of the mortar joints or by the compressive strength of the masonry. Referring to FEMA 356, the expected shear strength of horizontal mortar joints in existing masonry walls is determined by equation (3). The shear bearing capacity of existing masonry when controlled by the strength of the mortar is determined by equation (4). According to the equivalent diagonal bracing model in the previous section as determined in Figure 2 the w/2 diagonal bracing area is tw x w/2, then the compressive strength of the equivalent diagonal bracing determined by the expected mortar strength can be determined as shown in equation (5). The strength determined by equation (5) is compared with the actual strength f of the existing masonry wall, if f is less than fm, then the damage to the existing masonry wall is controlled by the compressive strength of the masonry and vice versa, by the bond strength of the mortar.

$$v_{me} = 0.75(v_{te} + \frac{P_{ce}}{A_n}) \tag{3}$$

In equation (3), v_{me} represents the expected shear strength of the horizontal mortar joints, vte represents the average shear strength of the horizontal mortar joints, Pce represents the vertical pressure applied to the masonry wall and An represents the net mortar area on the existing masonry.

$$V_{inf} = A_n v_{me} \tag{4}$$

In formula (4), V_{inf} represents the shear bearing capacity of the existing masonry controlled by the mortar strength.

$$f_m = \frac{2V_{inf}}{wt_w \cos\theta} \tag{5}$$

In equation (5), f_m indicates the calculated compressive strength of the diagonal brace when controlled by the strength of the grey joints, and θ indicates the angle between the lower end of the equivalent diagonal brace and the horizontal plane.

When the damage of the existing masonry is controlled by the compressive strength of the masonry, a Trilinear type concrete material principal considering strength loss is used in Perform-3D for equivalence in order to facilitate the calculation of the elastic-plastic phase. The skeleton curves used in Perform-3D are shown in Figure 3. As the principal structure of the masonry material is related to a variety of factors such as the properties of the blocks and the properties of the mortar, the specific parameters can be taken in conjunction with the relevant code regulations and, if necessary, determined through tests. Inelastic 1D Concrete Material was used in Perform-3D to simulate the masonry material for the equivalent diagonal bracing, and the Concrete Strut component was used to simulate the equivalent diagonal bracing.

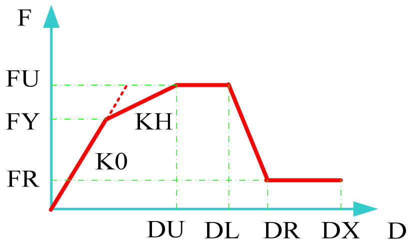

Fig. 3. Skeleton curve in Perform-3D

Based on the results of the experimental study, the performance level [15] [16] of the existing masonry walls can be divided as shown in Table 1, and the performance level and damage status of the structural columns and ring beams of the prefabricated RC wall panels and the existing masonry walls are evaluated according to the reinforced concrete elements [17].

Table 1. Performance levels and macroscopic description of masonry structures and corresponding inter-storey displacement angles

Performance level	Description of limit states for different performance levels	Corresponding interlayer displacement angle
For normal use	**The existing wall as a whole is in the elastic working phase, with minor diagonal cracks starting to appear and the load is about 40% to 60% of the ultimate load.**	θ≤1/2500
For medium damage	**The load-bearing wall loses some of its stiffness and strength and enters the elasto-plastic working phase, where diagonal cracks begin to develop, stepped cracks in diagonal directions appear near the form centre of the wall and fine cracks extend to the structural columns that restrain the wall.**	1/2500＜θ≤1/900
When life is safe	**The load-bearing wall loses most of its strength and stiffness and enters an elasto-plastic working phase, with new cross cracks appearing on both sides of the wall and fully developed, and the load dropping to about 90% of the ultimate load, but not to a state of collapse.**	1/900＜θ≤1/250
When it collapsed	**Complete loss of load bearing capacity**	θ＞1/250

3 Conclusions

RC wall panels can effectively reduce the wet-work construction in the reinforcement of existing masonry structures and improve the timeliness of the reinforcement of existing masonry structures. The effectiveness of RC wall panels in the strengthening of existing masonry structures is significant as analyzed in this paper. This paper demonstrates the effectiveness and applicability of using precast assembled reinforced concrete wall panels to reinforce existing conventional masonry structures by means of finite element methods in conjunction with existing research results. This paper provides a theoretical basis for the future use of RC wall panels for strengthening existing masonry structures. Subsequently, in order to further assess the seismic performance of existing ordinary masonry structures strengthened using precast RC wall panels, the treatment and macroscopic index requirements for performance assessment during elasto-plastic analysis of existing ordinary masonry are discussed. The main conclusions of this paper are as follows:

(1) The macroscopic index requirements for performance assessment of existing regular masonry structures under rare earthquakes are determined, and the limit value of the interstorey displacement angle under rare earthquakes should not be greater than 1/250.

(2) The principle of defining the parameters of equivalent diagonal bracing and the requirements for evaluation when using PERFORM-3D for the calculation of existing regular masonry structures under rare earthquakes. The axial compression truss unit can be simulated in PERFORM-3D under rare seismic action.

(3) The use of prefabricated RC wall panels can improve the integrity of the existing regular masonry structure, and can reduce the damage of the existing regular masonry structure under rare earthquakes, improve its overall structural capacity, and make its interstorey deformation under rare earthquakes relatively uniform.

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