Analysis’s Research Status of Reinforcement Technology of PP-Bands in Masonry Structures

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Abstract. Reinforcement with polypropylene bands is a newly arisen seismic technique. it can effectively improve the ultimate shear and flexural capacity and seismic performance of the structure, sudden collapse of whole structure can also be avoided, so it is especially suitable for the seismic reinforcement of rural masonry structures. In recent years, it has been gradually applied in the reinforcement and restoration of masonry structures. Based on the latest development of research, the influence of reinforcement with polypropylene bands (pp-bands) on the shear, flexural and seismic behavior of masonry structure were systematically introduced. The influence of the main reinforcement parameters such as mesh size, grid layout direction, connection mode, connection strength and mortar layer on the reinforcement effect were summarized. Deficiency of the current research and the key problems that need to be solved were pointed out. Through the study on research status of reinforcement technology of pp-bands in masonry structures, references for further research on the strengthening technology of pp-bands and the seismic reinforcement of rural masonry buildings in China were given.

Keywords: reinforcement with pp-bands, masonry structures, research status, seismic performance, rural building.

1. Introduction

Earthquakes occur frequently in China and earthquake disasters are very serious. In recent years, Ludian earthquake, Yushu earthquake and Wenchuan earthquake caused a large number of destruction of masonry buildings, serious casualties and economic damage [1]. As one of the important structural types of building in China, masonry structure is widely used. However, due to its large dead weight, the material is brittle and has shortcomings such as low tensile strength, shear resistance and flexural capacity. The seismic performance is generally poor [2]. Therefore, it is an urgent problem to improve the seismic capacity of masonry buildings by conducting seismic strengthening and retrofitting.

At present, the commonly used reinforcement methods of masonry structure include reinforced concrete mortar surface, outer clad steel, buttress column and fiber reinforcement, etc. However, there are some shortcomings of these reinforcement methods. Such as long construction period and wet working time, expensive price, and beauty of the building. Therefore, this paper summarizes and analyzes a new reinforcement method of masonry pp-bands reinforcement.

The pp-bands reinforcement is simple, efficient, cheap, easy to construct and can significantly improve the building's seismic behavior. So it is suitable for seismic reinforcement of masonry structures. Therefore, in view of the severe situation about earthquake resistance of masonry structures
in china at present. It can provide a new idea for seismic strengthening of buildings by carrying out the research on the reinforcement of pp-bands and it has important engineering significance and research value.

2. Brief Introduction of PP-Bands Reinforcement Technology

2.1. Material Characteristics of PP-Bands

The main material of the pp-bands is polyethylene, polypropylene resin, etc. Compared with the traditional reinforcing materials, the pp-bands has following outstanding advantages.

(1) It has good physical and mechanical properties, such as good plasticity, strong tensile strength, resistance to bending fatigue and good tensile impact performance. Due to the masonry structure has the disadvantages of brittleness, poor tensile resistance, shear resistance and bending resistance. Therefore, the combination of the pp-bands and the masonry can make full use of their respective performance advantages.

(2) It is convenient to construct, such as high efficiency, less construction occupied space and less wet operation. The construction procedure is simple and the requirements for operational skills are not high.

(3) It is light and high strength; the proportion is small. It does not occupy the using space and affect the architectural beauty.

(4) Its price is low, the cost is about 0.85-3.4 USD/m², and it can be recycled for daily use.

2.2. Process of Reinforcement

The reinforcement method of pp-bands was put forward by Mayorca P [3-4] of Tokyo University, Japan. The main idea is to weave the pp-bands into a net and then lay the net and tie it on the wall to strengthen the wall. The main reinforcement process is shown in Figure 1.

![Reinforcement technical process of polypropylene bands](image)

**Figure 1.** Reinforcement technical process of polypropylene bands [3-4].

3. Research Progress on Reinforcement Technology of Packing Belt

3.1. Experimental Study on Shear Behavior of Masonry Strengthened with PP-Bands

As early as 2003, Mayorca P et al. [3-4] put forward the experiment of shear strengthening of masonry structure by using pp-bands material. the experimental results show that the reinforcement technology of pp-bands can obviously improve the shear strength and stiffness of masonry. Shear strength
increased by 42%. The influence of different mesh sizes (45mm and 90mm) and different connection degree (all connections and partial connections) on the reinforcement effect were analyzed by numerical simulation with finite element software. It is found that the stronger the mesh is, the stronger the connection degree is and the reinforcement effect is more remarkable. Since then, Sathiparan N and Meguro K [4] have further studied the effect of mesh size on the shear strength of the wall by in-plane diagonal shear test. The reinforcement using four different strap widths (33 mm, 40 mm, 50 mm, 66 mm). The results show that the residual strength and stiffness of the wall after initial cracking are inversely proportional to the spacing of the strap. But the relationship between the reinforcing effect and the spacing of the strap is no longer obvious after exceeding the optimal spacing. In 2013, Sathiparan N et al. [5] further carried out the in-plane shear test of masonry wall strengthened by net of pp-bands and studied the influence of pp-bands direction, wall connection mode and the surface layer of the mortar on the reinforcement effect. The results show that the initial strength of the horizontal arrangement is lower than that of the 45° oblique arrangement. In 2014, Saleem MU [6] used the Applied Element Method (AEM) method to numerically simulate the in-plane shear of six sheets of reinforced masonry walls without reinforcement, strap reinforcement, CFRP and strapping. This method has a good simulation effect on the initial test results of the wall strengthened by pp-bands but is not ideal for the large deformation stage. In 2015, Saleem MU [7] carried out the research of fiber composite material and the composite reinforcement of masonry structure with pp-bands. By comparing the in-plane shear test results of eight masonry structures strengthened with FRP, pp-bands, FRP and pp-bands. It is concluded that the initial strength, deformation capacity and ductility of the wall can be improved effectively by FRP and pp-bands composite reinforcement.

In 2011, Zeng Yinzhi [8] carried out research on steel angles and pp-bands reinforcement methods for brick walls with low mortar strength in masonry structure buildings. The low cyclic loading test is carried out to compare and study the bearing capacity and deformation performance of two walls under horizontal force. The seismic behavior of the wall can be improved obviously by using the pp-bands reinforcement method. After the reinforcement, the shear capacity of the wall increased by 29% and the ultimate displacement increased by 324%. This study provided meaningful achievements for the pp-bands reinforcement technology and proposed a new idea for the fixed method of the net of pp-bands.

3.2. Experimental Study on Out-of-Plane Flexural Behavior of Masonry Strengthened with PP-Bands

In 2008, Sathiparan N [4] carried out an experimental study on the out-of-plane flexural properties of sintered brick masonry strengthened with pp-bands and analyzed the flexural strength, stiffness and ductility of sintered brick and unsintered brick before and after reinforcement. The results show that the out-of-plane flexural behavior of masonry structure can be significantly enhanced by using pp-bands reinforcement technique and the mid-span deflection of the strengthened masonry wall is increased from 2.8mm to 70.0mm. Although the whole performance of sintered brick is better than that of unsintered brick but the utilization ratio of unsintered brick is higher than that of unsintered brick. After that [5], they further studied the effect of temperature on the tensile strength of the pp-bands material and the effect of the surface coating mortar. The experiment showed that the tensile strength of the pp-bands decreased with the increases of temperature. The surface coating mortar not only ensures the integrity of the pp-bands and the wall but also protects the pp-bands from ultraviolet radiation and severe temperature changes.

In 2015, Saleem MU [7] carried out the research of fiber composite material and pp-bands composite strengthening masonry structure. It was found that the composite material not only improved the initial strength and deformability of the masonry, but also improved the whole performance of the masonry. In all types of FRP and pp-bands composite reinforcement, the full strength of FRP is not fully utilized. So the relatively cheap GFRP and pp-bands composite is more suitable for masonry structure reinforcement. In 2016, Andreas T [9] analyzed the bending along the vertical axis and bending along the horizontal axis through the out-of-plane bending test and the influence of the mesh spacing of the net of pp-bands are analyzed in detail. The experimental results
show that bending along the vertical axis and along the horizontal axis can significantly improve the flexural performance of masonry structure, but there is no significant difference between them. The flexural bearing capacity decreases with the increase of the grid spacing of the pp-bands.

3.3. Experimental Study on Seismic Behavior of Masonry Strengthened with PP-Bands
In 2009, Mayorca P [10] studied the seismic behavior of masonry buildings by means of test and numerical simulation. It was found that the ductility and energy dissipation capacity of strengthened masonry structures were significantly improved. The pp-bands reinforcement can effectively improve the structural integrity and prevent or delay the collapse of the structure. Since then, Sathiparan N and Meguro K [11-13] had used 1/4 scale of wood truss roof masonry house, stone building and arched roof adobe house to carry out shaking table experiment. The test results show that the hysteresis loop of the structure is full, the deformation capacity is strengthened, the ductility is increased, and the skeleton curve drops smoothly which improves the seismic performance of the whole structure effectively and avoids the brittle failure of the structure after reinforced with pp-bands. The reinforcement method is simple, economical and practical.

In 2016, Saleem MU [14] studied the seismic response of masonry buildings reinforced with fiber and pp-bands under the shaking table. After several reinforcement tests, the best reinforcement rate of FRP was 0.06%. The experimental results show that the combination of FRP and pp-bands is obviously better than that of using FRP and pp-bands alone. It can improve the seismic performance of the structure significantly.

In China, in 2010, Sun Baitao [15] carried out a series of shaking table model tests for single-story masonry houses (a total of 7 single-layer concrete block masonry structure models, based on 1:3 scale of which 3 are reinforced with pp-bands, 1 with partial reinforcement and 3 with no reinforcement). In 2011, Yao Xinqiang [16] conducted a study on the shaking table model test of the ring-beam structure column and the ring-free beam structure column respectively and compared the seismic performance of the model with and without the pp-bands reinforcement. Some suggestions were put forward for the seismic strengthening, design and construction of the building through numerical simulation. It is concluded that the reinforcement with the pp-bands can effectively enhance the seismic performance of the masonry structure especially the collapse resistant capacity. Since then, Bai Xiaoxia [17] based on the experiments of Zeng Yinzhi and carried out numerical simulations of houses. It is considered that the two different reinforcement methods can improve the bearing capacity and whole performance of masonry structure. However, the material price of the pp-bands is much cheaper and the reinforcement construction process is relatively simple. It is more suitable for the reinforcement of the masonry structure buildings.

4. Insufficient Research at Present
It can be seen from the above meaningful research work that the effectiveness and feasibility of the pp-bands reinforcement method can be fully verified, but there are still some shortcomings as followings.

(1) Seismic behavior and reinforcement mechanism of masonry strengthened with pp-bands
The failure of masonry structure reinforced by pp-bands is a very complicated process and the common action mechanism between the pp-bands and masonry under seismic reciprocating action is still unclear. Therefore, it is necessary to carry out further systematic research on seismic behavior and reinforcement mechanism of masonry strengthened with pp-bands.

(2) Evaluation method for seismic performance of masonry structure reinforced with pp-bands
How to evaluate and determine the seismic performance of the reinforced structure, the corresponding seismic performance evaluation indicators and the factors such as the reinforcement material, dosage and arrangement is the key issues that must be solved. At present, there are few researches on seismic performance evaluation of masonry structure reinforced by pp-bands. Therefore, it is necessary to develop a more versatile method to evaluate the seismic performance of masonry structures reinforced with pp-bands.
(3) Design theory of pp-bands reinforcement

The reinforced wall is composed of masonry, pp-bands and surface mortar. How to establish the reasonable force analysis model of the reinforced wall and how to calculate the bearing capacity of the strengthened wall are the key problems to be solved in the seismic reinforcement design. No research has been carried out on the theory of reinforcement design for masonry structures.

(4) Finite element analysis of masonry wall and structure reinforced by pp-bands

The key of finite element analysis of strengthened masonry structure is how to simulate the mechanical properties of blocks, mortar and strengthening materials in the reinforced structure and the interaction between various materials accurately. At present, most of the analysis in this aspect simplifies the masonry into an isotropic homogenous material, ignores the macroscopical composition between the block and mortar, and slip between the reinforcement material and the masonry. Therefore, it is necessary to establish separate fine finite element model to study the interaction mechanism between mortar, block and pp-bands in masonry.

(5) Optimization and specification of packing tape reinforcement technology

At present, there are few researches on the strength and thickness of the wall surface, the number and distribution requirements of the connecting points between the pp-bands net and the wall, the connecting mode between the pp-bands net and the wall. At the same time, it is found that some nonstandard operation may cause damage to the wall and affect the reinforcement effect when drilling in the previous series of shaking table tests. Therefore, it is necessary to standardize and optimize the technology of pp-bands reinforcement to formulate a reasonable implementation scheme and specific implementation rules.

5. Conclusions and Recommendations

In this paper, the current research situation of masonry structure reinforced by pp-bands is summarized and the influence of the reinforcement on shear, flexural and seismic behavior of masonry structure is analyzed. The conclusions and suggestions are obtained as followings.

The strengthening technology of pp-bands can improve the shear, bending and seismic performance of the structure significantly. The shear bearing capacity, cracking load, ultimate load, out-of-plane flexural bearing capacity and ductility of the strengthened masonry structure have been greatly improved and the integrity of the structure has been further improved.

The main reinforcement parameters, such as mesh size, grid layout direction, tensile connection mode, tensile strength, mortar surface layer have certain influence on the reinforcement effect. In the boundary grid rate, the higher the mesh density, the better the reinforcement effect. The horizontal arrangement is better than the 45° oblique arrangement. Mortar surface layer can further enhance the integrity of packing tape and structure and protect the pp-bands from the influence of external factors to some extent.

As an emerging reinforcement method, the seismic behavior of masonry structure reinforced by pp-bands need to be studied systematically and deeply. The experiments need to be conducted to clarify the interaction mechanism between the pp-bands and the wall, reveal the reinforcement mechanism of the pp-bands and establish a seismic performance evaluation method, optimize and standardize the reinforcement technology of pp-bands. These results can be verified by appropriate finite element modeling method. Therefore, the seismic strengthening effect of the pp-bands can be maximized and the seismic capacity of the masonry structure can be improved. It is of great social significance for improving the level of earthquake preparedness and disaster reduction in China.

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