Security Analysis of Rock Wool Board Exterior Wall Insulation System Under the Effect of Wind Load

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Abstract: In recent years, several accidents occurred about rock wool board thin plastering exterior insulation system is blown off by strong wind in our country, affecting the popularization and application of the system in the project. To study on rock wool board exterior wall insulation system security, this paper take a high-rise building in Jinan as the research object, and research results show that under the condition of meeting the existing rules technology, the theoretical calculation value of wind load bearing capacity is far greater than the wind load bearing capacity design value of rock wool board thin plastering system. The main technical parameters affecting the wind resistance of the system are tested in the field on this basis, test results show that test values of rock wool board and grassroots bonding area bonding strength is far less than the limit value, but the system also has a certain security reserve when compared with the design value of wind load .Finally, based on the comparative analysis of the theoretical and experimental results, we put forward the corresponding technical measures to improve the safety of the rock wool board thin plastering exterior insulation system undering the action of wind load

Keywords: Wind Load; Rock Wool Board Exterior Wall Insulation System; Security Analysis

1. Introduction

In recent years, many accidents have occurred in China where the rock wool board thin - plaster exterior wall external insulation systems were blown off by strong winds, which has affected the popularization and application of this system in engineering projects. With the continuous improvement of building energy - saving technologies in China, the building exterior wall external insulation system has been very commonly used in new buildings and the renovation of existing buildings. The external insulation system shows advantages in building energy - saving and improving the indoor environment. Rock wool boards, as Class A non - flammable fire - proof insulation materials, also have the advantages of low water absorption and hygroscopicity, no thermal expansion or contraction, and aging resistance, providing buildings with multiple performances such as effective thermal insulation, energy - saving, noise reduction and protection against extreme climates. However, in recent years, during the use of the rock wool board exterior wall external insulation system, problems such as cracking on the exterior wall surface, falling off of the insulation boards, and indoor water seepage are likely to occur. For example, on March 31, 2012, Urumqi encountered windy weather, which caused the exterior wall insulation materials of a high - rise residential building to fall off, resulting in 2 deaths; on March 22, 2013, a building in Shenyang was damaged by strong winds, causing nearly 10 square meters of the exterior wall on the 28th floor of the building to fall off and vehicles to be damaged; on May 7, 2014, Jinan encountered windy weather, and about twenty to thirty square meters of the exterior wall insulation materials on the west side of a high - rise residential building in Jinan fell off, causing damage to multiple vehicles. In view of the influence of wind loads on the rock wool exterior wall external insulation system, a safety analysis is carried out in combination with an actual engineering case in Jinan.

2. Project Overview

This engineering project is located on the west side of Jiluo Road and on the south side of Donglu of the Automobile Factory in Jinan. There are 21 floors above the ground, among which the floors below and including the 4th floor are for commercial use, and those above the 4th floor are for residential use. The total above - ground construction area is 11,159.96

square meters, and the building height is 69.66 meters. The structural form of this project is a frame - shear wall structure for earthquake resistance, and the seismic fortification intensity is six degrees. The fire protection classification of this project is a high - rise building of the first category. The fire resistance rating of the above - ground part is first - class, and the designed service life is 50 years. This project adopts the rock wool board thin - plaster exterior wall external insulation system, and the thickness of the rock wool board is 60mm. The exterior wall finish is made of stone - like paint.

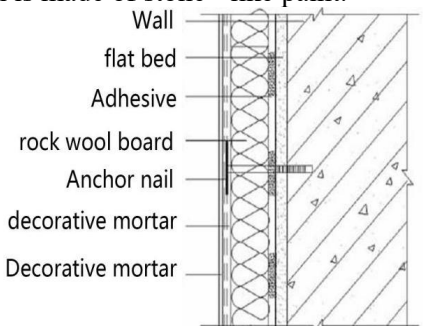

Figure 1. Structural Diagram of Rock Wool Board Thin - Plaster Exterior Wall External Insulation System.

3. Theoretical Calculation of Wind Load on the Rock Wool Board Exterior Wall External Insulation System

3.1 Force Analysis of the Rock Wool Board Thin - Plaster System

In the rock wool board thin - plaster system, the rock wool board is adhered to the wall with adhesive on the leveled base course. After applying the first layer of rendering mortar and pressing in the first layer of alkali - resistant fiberglass mesh, it is fixed with anchor bolts. Then, the second layer of rendering mortar is thinly applied and the second layer of alkali - resistant fiberglass mesh is pressed in. After thinly applying the third layer of rendering mortar, the finish layer is processed [3]. In this system, the connection with the wall base course mainly depends on anchoring, supplemented by bonding. From the force analysis diagram of the rock wool board thin - plaster exterior wall external insulation system (Figure 2), the external loads on the system are wind load and the self - weight of the system. As can be seen from Table 1, the self - weight of the system per square meter is 0.222 k, which is relatively small. The main factor affecting the safety of the system is the wind load. The wind load is the wind suction acting on the outer surface of the system, perpendicular to the wall surface and outward. Eventually, it is transmitted to the base wall through the adhesive force of the adhesive and the anchoring force of the plastic anchors.

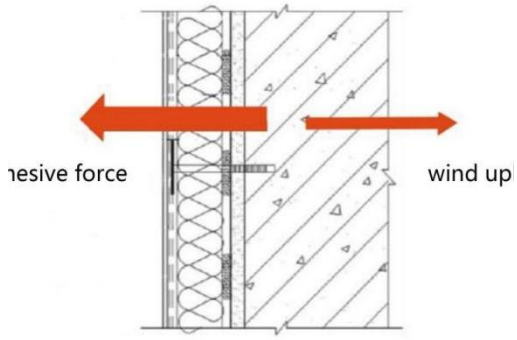

Figure 2. Force Analysis Diagram of Rock Wool Board Thin - Plaster Exterior Wall External Insulation System.

Table 1. Self - weight of Each Component in the Exterior Wall External Insulation System.

	Rock wool	Rendering mortar	Coating finish layer Total G.
Density	160kg/m^3	1800kg/m^3	/ /
Thickness	60mm	7mm	/ /
Mass	9.6 kg/㎡	12.6kg/㎡	/ 0.222kN/㎡

2.2 Wind Load Analysis of the Rock Wool Board External Insulation System

2.2.1 Calculation of Wind Load

When calculating the standard value of wind load acting on the vertical plane of a building according to GB50009 - 2012 "Load Code for the Design of Building Structures", the calculation of the building envelope should be determined by the following formula.

$\omega_k = \beta_{gz}\mu_{sl}\mu_z\omega_o$

In the formula: — standard value of wind load, kN/㎡; — gust factor at height Z; — shape coefficient of wind load; — coefficient of wind pressure varying with height; — basic wind pressure, kN/㎡.

The basic wind pressure in Jinan is: 0.30 KN/㎡ (10 - year recurrence interval); 0.45 KN/㎡ (50 - year recurrence interval); 0.50 KN/㎡ (100 - year recurrence interval). In this calculation, according to the 100 - year recurrence interval, the basic wind pressure is taken as 0.50 KN/㎡. The ground roughness category is taken as C, = 1.28. The shape coefficient of wind load = - 2.0 (the negative sign indicates negative pressure).

The gust factor at a height of 70m = 1.75. The standard value of wind load = 1.75 * - 2.0 * 1.28 * 0.5 KN/㎡ = - 2.24 KN/㎡. The partial coefficient of wind load is taken as 1.40, so the design value of wind load perpendicular to the building surface is: 1.4×(－2.24) = - 3.136 kN/㎡.

2.2 Calculation and Value - taking of the Adhesive Force of Rock Wool Boards and the Anchoring Force of Anchor Nails.

According to Article 4.1.1 of DBJ/T 14 - 073 - 2010 "Technical Specification for the Application of Rock Wool Board Exterior Wall External Insulation System" [4], after the weatherability test of the rock wool board composite slurry exterior wall external insulation system, its tensile bond strength should be ≥50 kPa; there should be no less than 6 plastic anchors per square meter of the wall surface. The diameter of the anchor disk is greater than 80 mm, the effective fixing depth in concrete should be no less than 25 mm, and in masonry walls no less than 50 mm. The standard value of the tensile bearing capacity of a single anchor is no less than 0.3 kN, and the number of anchors per unit area is no less than 6. The rock wool board should be preferably pasted by the full - adhesion method without cavities, and the cavity - existing pasting method is not allowed. The bonding area should be no less than 60%. Based on the minimum technical parameter requirements of the specification for bonding strength and bonding area, as well as the tensile bearing capacity of anchors and the number of anchors, the sum of the adhesive force and the anchoring force of the exterior wall external insulation system in the horizontal direction is: F = 50 * 60%+6 * 0.3 = 31.8 kN/㎡ [5 - 6].

2.3 Calculation and Analysis of the Safety of Rock Wool Board Exterior Wall Insulation System under Wind Load

The design value of wind load perpendicular to the building surface is - 3.136 kN/㎡. The sum of the bonding and anchoring forces in the horizontal wind direction per square meter of the exterior wall external insulation system is 31.8 kN/㎡. According to the design value of wind load on the rock wool board perpendicular to the building surface, as well as the bonding force and anchoring force of the rock wool board, the safety factor of the rock wool board thin - plaster exterior wall external insulation system of this building under the action of negative wind pressure can be obtained: 31.8/3.136 = 10.14 [7 - 8]. Therefore, when the construction quality meets the requirements of current codes and regulations, the resistance of the rock wool board system is far greater than the design value of wind load, and the rock wool board thin - plaster exterior wall external insulation system has a large safety margin [9 - 10].

3 Field Tests

3.1 Pull - out Tests for Anchor Bolt Bearing Capacity

According to the requirements of GB 50411 - 2007 "Code for Acceptance of Construction Quality of Building Energy Efficiency" [11], on - site sampling tests were carried out on the pull - out bearing capacity of the plastic anchors used in this project, as shown in Table 2.

Table 2. Pull - out Bearing Capacity of Plastic Anchors

Test No.	Detection Location	Matrix Type	Pull - out Force (kN)
1	xterior wall at the intersection of 1/K axis and 1/2 axis on the fifth floor	Concrete	0.83
2	Exterior wall between K - L axes on the fifth - floor 14 - axis	Concrete	1.26
3	Exterior wall on K - L axes on the fifth - floor 14 - axis	Concrete	1.33
4	Exterior wall between K - L axes on the fifth - floor 14 - axis	Concrete	0.89
5	Exterior wall between K - L axes on the fifth - floor 14 - axis	Concrete	1.12
6	Exterior wall between K - H axes on the tenth - floor 2 - axis	Concrete	1.25
7	Exterior wall between K - H axes on the tenth - floor 2 - axis	Concrete	0.87
8	Exterior wall between K - H axes on the tenth - floor 2 - axis	Concrete	0.76
9	Exterior wall between K - H axes on the tenth - floor 2 - axis	Concrete	0.82

10	Exterior wall between H - K axes on the seventeenth - floor 4 - axis, aerated concrete block	Aerated Concrete Block	0.08
11	Exterior wall between H - K axes on the seventeenth - floor 4 - axis, aerated concrete block	Aerated Concrete Block	0.09
12	Exterior wall between K - L axes on the twenty - first - floor 1/2 - axis	Concrete	1.32
13	Exterior wall between K - L axes on the twenty - first - floor 1/2 - axis	Concrete	1.12
14	Exterior wall between K - L axes on the twenty - first - floor 1/2 - axis	Concrete	1.74

It can be known from the experimental test results that the pull - out force of the anchors with the specification of Φ8×142mm in the aerated concrete block matrix of the exterior wall is between 0.08kN and 0.09kN, which does not meet the requirement of "the standard value of the anchor bolt pull - out bearing capacity shall be not less than 0.30kN" in DBJ/T 14 - 073 - 2010 "Technical Specification for the Application of Rock Wool Board Exterior Wall External Insulation System". The pull - out force of the anchors with the specification of Φ8×142mm in the concrete matrix of the exterior wall is between 0.76kN and 1.74kN, which meets the requirement of "the standard value of the tensile bearing capacity of the anchor bolt shall be not less than 0.30kN" in DBJ/T 14 - 073 - 2010 "Technical Specification for the Application of Rock Wool Board Exterior Wall External Insulation System". The average value of the measured tensile bearing capacity of the anchors is 0.96kN [12].

3.2 Test on the Bonding Strength between the Insulation Layer and the Base Wall.

According to the requirements of GB 50411 - 2007 "Code for Acceptance of Construction Quality of Building Energy Efficiency", on - site sampling point detection was carried out for the tensile bonding strength between the insulation layer and the base wall of this project (as shown in Table 3). The on - site detection results show that the tensile bonding strength between the insulation layer and the base wall of this project is between 2.8 kPa and 30.8 kPa, with an average value of 11.62 kPa. According to Article 4.1.1 of DBJ/T 14 - 073 - 2010 "Technical Specification for the Application of Rock Wool Board Exterior Wall External Insulation System", after passing the weatherability test, the tensile bonding strength of the rock wool board thin - plaster exterior wall external insulation system should be ≥ 50 kPa. It can be known from the technical index requirements for the rock wool board thin - plaster exterior wall external insulation system in the specification that the on - site tensile bonding strength between the insulation layer and the base wall of this project is far less than the specification limit.

Table 3. Tensile Bonding Strength between Insulation Layer and Base.

Test No.	Detection Location	Pull - out Strength (kPa)	Failure Location
1	Exterior wall at the intersection of 1/K axis and 1/2 axis on the fifth floor	15.4	The failure part is between the insulation layer and the adhesive.
2	Exterior wall between K - L axes on the fifth - floor 14 - axis	30.8	The failure part is between the insulation layer and the adhesive.
3	Exterior wall between K - H axes on the tenth - floor 2 - axis	3.2	The failure part is in the insulation layer
4	Exterior wall between H - K axes on the seventeenth - floor 4 - axis	2.8	The failure part is in the insulation layer
5	Exterior wall between K - L axes on the twenty - first - floor 1/2 - axis	5.9	The failure part is in the insulation layer

2.5 The Number of Anchors Per Square Meter.

According to the requirements of GB 50411 - 2007 "Code for Acceptance of Construction Quality of Building Energy Efficiency", on - site sampling inspection was carried out for the number of plastic anchors used in this project

within the unit area. The results are detailed in (Table 4). The on - site inspection results show that the number of anchors per unit area in this project ranges from 2.9 to 11.7, and the average number of anchors per unit area is 6.8. Referring to the rock wool board thin - plaster exterior wall external insulation system, it does not fully meet the requirement in Article 6.4.1.4 of DBJ/T 14 - 073 - 2010 "Technical Specification for the Application of Rock Wool Board Exterior Wall External Insulation System" that there shall be no less than 6 anchors per square meter of the wall surface [13].

Table 4. Number of Anchors per Square Meter.

Test Number	Detection Location	Number of Measured Anchors	Actual Area	Number of Anchors per/m²
1	Exterior wall at the intersection of 1/K axis and 1/2 axis on the fifth floor	3	0.72	4.2
2	Exterior wall between K - L axes on the 14th axis of the fifth floor	7	0.60	11.7
3	Exterior wall between K - H axes on the 2nd axis of the tenth floor	4	0.74	5.4
4	Exterior wall between H - K axes on the 4th axis of the seventeenth floor	2	0.68	2.9
5	Exterior wall between K - L axes on the 1/2 axis of the twenty - first floor	6	1.03	5.8

3.3 Pasting Area of Rock Wool Board

According to the requirements of DBJ/T 14 - 073 - 2010 "Technical Specification for the Application of Rock Wool Board Exterior Wall External Insulation System", for the rock wool board pasting, the full - adhesion method without cavities should be preferably adopted, and the adhesion method with cavities is not allowed; the strip - adhesion method can also be adopted, and the gluing area shall not be less than 60%. After taking pictures of the distribution of adhesives after the rock wool board fell off on the construction site of this project, the pixel method was used for calculation. It can be seen from the on - site photos of the distribution of adhesives on the exterior wall of this project that the strip - adhesion method was not used for pasting the rock wool board, and most of them did not conform to the frame - adhesion method either, which belonged to non - standard methods. The average value of the pasting area of the selected calculation parts was 50.35%, which did not meet the relevant technical index requirements of DBJ/T 14 - 073 - 2010 "Technical Specification for the Application of Rock Wool Board Exterior Wall External Insulation System".

Based on the above - mentioned test data, since the on - site test values of the bearing capacity of anchors are all greater than the standard limit value of 0.3 kN, for the sake of conservatism, 0.96 kN is taken in the calculation, and the average value of 11.62 kPa from the test is taken as the bonding strength between the insulation layer and the base wall; it has been found on - site that there are no fewer than 6 plastic anchors per square meter of the wall surface, so 6.8 anchors per square meter are taken in the calculation, and the bonding area is taken as 50.35%. Considering the discreteness of the test values of the bonding force of the rock wool board and the anchoring force of the anchors, the partial coefficients of the bonding strength between the board and the base and the bearing capacity of the anchors are taken as 1.2. Therefore, it can be known through on - site tests that the sum of the bonding and anchoring forces per square meter of the exterior wall external insulation system subjected to the horizontal wind direction is: F=(11.62 * 50.35%+6.8 * 0.96)/1.2 = 10.316 kN/㎡. By comparing the on - site test detection with the theoretical calculation, it can be known that the theoretical value is far greater than the detected value, and the safety factor of the theoretical calculation and the rock wool board thin - plaster insulation system is: 10.316/3.136 = 3.29. However, it is only 32.4% of the theoretical calculation value [13].

By comparing the design value of wind load of 3.136 kN/㎡ under the most unfavorable conditions with the measured value of the sum of the bonding force and the anchoring force detected on - site, which is 10.316 kN/㎡, it can

be known that the measured value is greater than the design value of wind load, and there is still a certain safety reserve in the wind - load - resistant design of the rock wool board exterior wall external insulation system [14 - 15].

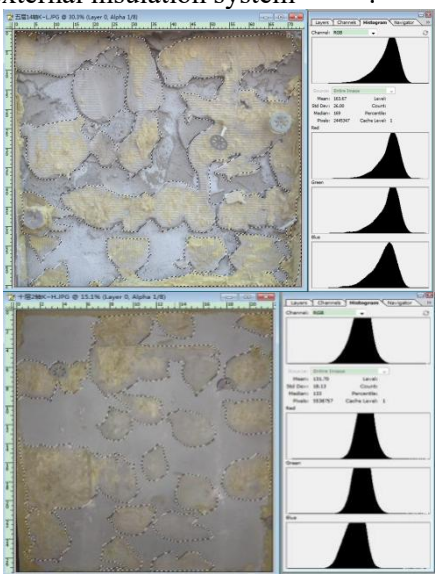

Figure 3. Calculation of the Bonding Area by the Pixel Method

4 Conclusion

1.According to the theoretical calculation and analysis, compared with the wind load, the self - weight of the external thermal insulation system of rock wool board on the exterior wall is relatively small, and its influence on the safety of the external thermal insulation system can be ignored. Therefore, when the construction quality meets the requirements of current codes and regulations, the resistance of the rock wool board system is far greater than the design value of the wind load, and the external thermal insulation system of rock wool board with thin - plaster on the exterior wall has a large safety reserve.

2.It can be known from the on - site test and detection that the measured value of the sum of the adhesive force and the anchoring force of the external thermal insulation system on the exterior wall of this project is 10.316 kN/㎡. Compared with the theoretical value of the wind load of 3.136 kN/㎡ under the most unfavorable conditions, although the building's external thermal insulation system on the exterior wall does not meet the requirements of the design code, it still has a certain safety reserve. Therefore, when using the external thermal insulation system of rock wool board on the exterior wall, its daily maintenance should be strengthened, and the usage condition of the exterior wall enclosure structure should be regularly inspected. Mark the positions where cracks and hollowing occur on the exterior wall and take timely maintenance and reinforcement measures to ensure the integrity and reliability of the system. When extreme weather such as strong winds and thunderstorms occurs, a conspicuous protective isolation sign should be set up below.

3.By comparing the measured value of 10.316 kN/㎡ of the sum of the adhesive force and the anchoring force of the external thermal insulation system of rock wool board on the exterior wall with the theoretical value of 31.8 kN/㎡, it can be seen that the measured value is only 32.4% of the theoretical value, which is far less than the limit value of the regulation. Through the comparative analysis of the theoretical and experimental results, it can be known that attention should be paid to the control of construction quality. First of all, when anchor bolts are used for anchoring, the diameter of the anchor bolt disc should be ≥80mm, and the anchor bolt should be anchored through the alkali - resistant glass fiber mesh. The effective anchoring depth of the base structure should be ≥30mm, and when the base is aerated concrete block, the anchoring depth should be ≥50mm. The number of anchor fittings in the negative wind pressure area of the building can be increased to 8 pieces/㎡. Secondly, according to the characteristics of the rock wool board, the strip - adhesion method should be adopted. Each rock wool board surface should be fully coated with an adhesive with a width of about 80 mm, and the thickness of the adhesive should be about 5mm - 12mm. The effective bonding area between the rock wool board in the negative wind pressure area and the base wall should be increased to more than 70%.

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