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Research on the Envelope Structure of Zero-carbon Substation Based on BIPV

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Abstract: In the environment of dual-carbon target, based on the design concept of zero-carbon substation, a kind of photovoltaic integrated prefabricated peripheral wall panel integrating high efficiency and low consumption, energy saving and environmental protection. The enclosed wall board can achieve the goal of zero carbon from three aspects: production, construction and use. In terms of production, recycled concrete is used; prefabricated wall panels are used for construction; in terms of use, prefabricated photovoltaic modules are integrated. On this basis, firstly, the bearing capacity analysis and test verification of the sandwich panel to provide a more comprehensive understanding of the stress performance of the sandwich panel and the wind load standard value to ensure the reliability of the photovoltaic modules, and finally, the integrated prefabricated peripheral wall panels to prove the feasibility of production and construction.

Keywords: zero-carbon substation, integrated wall panel, bending analysis, photovoltaic module.

1. Introduction

At the general debate of the United Nations General Assembly[1], President Xi Jinping solemnly announced a series of medium-and long-term goals and visions of China's carbon peak and carbon neutrality, and for the first time set the macro node goals of energy conservation and emission reduction and energy structure transformation, striving to achieve the carbon peak by 2030 and achieve carbon neutrality by 2060.

Zero-carbon substation is based on the existing energy saving and carbon reduction means, combined with the boundary conditions of the substation itself in carbon emission, formulate reasonable carbon reduction measures, and finally realize the near-zero carbon operation of the substation. Based on the design concept of zero-carbon substation, a photovoltaic integrated prefabricated exterior wall panel integrates high efficiency and low consumption, energy saving and environmental protection[2]. Combined with the advantages of prefabricated building components in the factory centralized assembly, the photovoltaic power generation system and building exterior wall board organic integration, both meet the requirements of the building peripheral parapet strong durable, also meet the requirements of using outside metope sunlight resources for photovoltaic power generation, at the same time with simplified construction technology, reduce costs and shorten the construction period and other significant advantages.

The traditional BIPV exterior walls of the above substation buildings, Although it can meet the performance requirements of the external wall, Can achieve the functional integration of building photovoltaic, But there are the following main problems: (1) from the perspective of building materials, Still using a lot of high-carbon emission materials such as steel and cement, Not fully utilizing the development achievements of green building materials technology, Lead to the carbon emission of the building materials production stage is difficult to be effectively reduced; (2) From the perspective of structure and construction mode, The external wall structure is complex, Field assembly of different kinds of materials or components, The photovoltaic module installation shall be completed in the second operation on site, As a general result, many construction processes, long construction cycle, large amount of consumables, easy damage to the wall and other problems, It highlights the disadvantage that photovoltaic modules and external wall components do not achieve real integration.

In general, the existing substation building BIPV envelope technology, did not make full use of green building materials technology, structural practice is more complex, need secondary operation, construction cycle is long, failed to achieve complete photovoltaic building integration, it is difficult to give full play to the photovoltaic system and envelope after the organic combination of comprehensive performance advantage, hindered the envelope play a due role in carbon reduction.

The photovoltaic integrated prefabricated peripheral wall panel adopted in this paper is a protective wall panel integrating high efficiency, low consumption and energy saving and environmental protection, which helps to achieve the goal of zero carbon from three aspects of production, construction and use. Through the test, finite element analysis and theoretical calculation, the comprehensive analysis of the force performance of the wall panel, and the calculation of photovoltaic modules and their connection, to ensure the safety and reliability of photovoltaic modules and their connection. Finally, the feasibility of the wall panel production and construction is verified through the process test.

2. Enclosure wall panel design

2.1. Integrated wall board construction

Based on the overall design requirements of zero-carbon substation and the performance requirements of peripheral wallboard, based on low-carbon inorganic material (recycled concrete[3,4]) Photovoltaic integrated peripheral wallpanel design scheme (as shown in Figure 1). The precast wall board consists of recycled concrete and W wire insulation board. W wire insulation board is placed in the W type abdominal wire mesh between polystyrene foam plastic insulation core material for insulation layer, with horizontal wire and W abdominal wire mesh on both sides of the-dimensional space wire mesh frame as the skeleton, through factory automation production equipment manufacturing, the horizontal wire and W wire are cold drawing wire, diameter of 2mm. Considering the connection of photovoltaic modules, a long square steel pipe is embedded on the outside of the wall.2

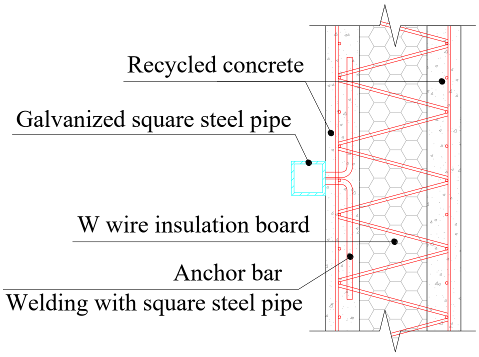

Figure 1: Structure of photovoltaic integrated peripheral clapboard

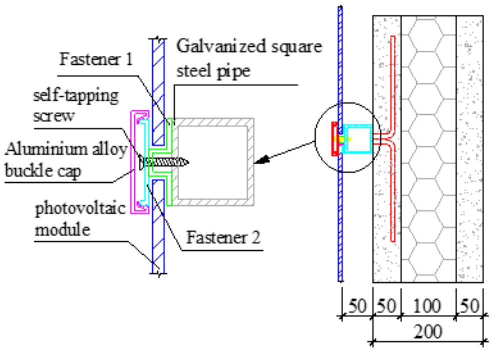

Figure 2: Photovoltaic module connection

2.2. Photovoltaic module connection and layout

The size of the photovoltaic module is 1200600, and the connecting nodes of the photovoltaic module are shown in Figure 2. Photovoltaic modules from bottom to top installation, installation of photovoltaic fixture 1 with glue or Angle support fixed on embedded square steel pipe, then placed photovoltaic modules, after placing photovoltaic fixture 2 with tapping screw and photovoltaic fixture 1 and steel pipe together, all photovoltaic module installation, buckle on aluminum alloy buckle, complete the installation of photovoltaic modules.

3. Analysis of retaining wall board bending

This chapter mainly analyzes the bending performance of the wall panels from the sandwich insulation wall board with recycled concrete, mainly from the theoretical calculation, finite element analysis and test results, and studies the combined stress performance of the sandwich insulation wall board.

3.1. fundamental principle

The recycled concrete used in this paper is C40, the replacement rate of recycled coarse aggregate is 100%, and its reduction coefficient is ασTake 0.85, so the design value of axial compression strength fc, Core tensile strength design value ftRespectively, are the 16.2N/mm2、1.45N/mm2. According to Technical Standard for Relaimed Concrete Structure JGJ / T 443-2018[5]In the relevant regulations, the mold is 2.6104N/mm2. Elastic modulus E of cold drawing steel wire in sandwich insulation wall panelsTake 2 virus 105N/mm2。

3.2. Theoretical analysis of wall board bending

3.2.1. Combined section calculation

The strain and stress of the concrete and the steel bar are shown in Figure 3[12]The bending bearing capacity of the positive section is calculated according to formula (1) (2) (3).

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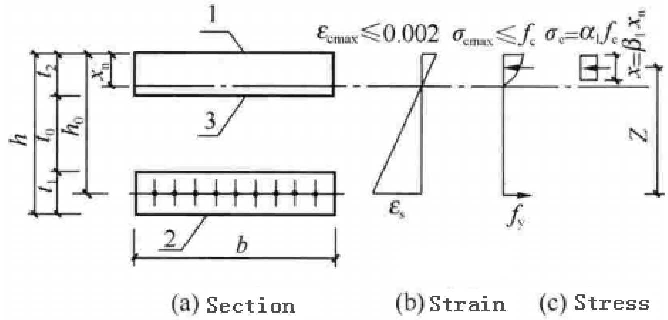


Figure 3: Combined section force

$M \leq A_s f_y z$	$M \leq A_s f_y z$	(1)
$x_n = A_s f_y / (b \beta_1 \alpha_y f_c)$	$x_n = A_s f_y / (b \beta_1 \alpha_y f_c)$	(2)
$z = h_0 - x/2 = h_0 - \beta_1 x_n / 2$	$z = h_0 - x/2 = h_0 - \beta_1 x_n / 2$	(3)

For the meaning of each letter, see the Technical Specification for application of JGJ / T 269-2012.

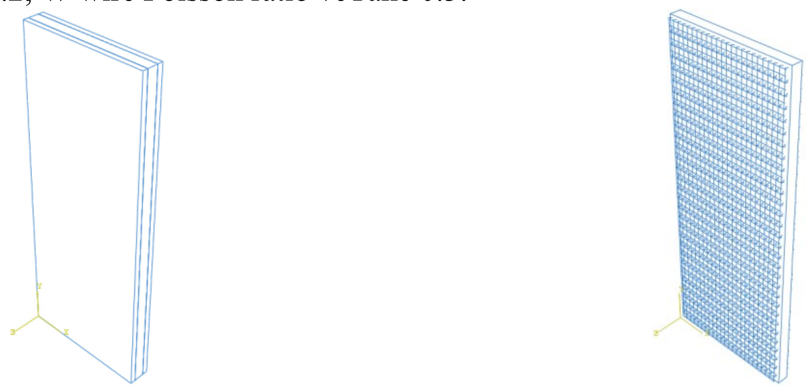
3.2.2. Uncombined cross-section calculation:

When the sandwich wall board is not combined, the bearing capacity of the wall board is calculated according to different rectangular sections.

3.3. Finite Element Analysis

3.3.1. Finite element model

The computational analysis software abaqus is used to establish the finite element solid model for elastic analysis. Due to the consideration, the combined force analysis of the UHPC board of the inner and outer leaves should be considered, so the solid model includes the W wire insulation board and the recycled concrete on both sides, and the W wire adopts the beam unit. In the model, the plane grid is divided by 20mm, and the thickness direction is divided by 10mm, so as to ensure the accurate calculation. The FEM model is shown in Figure Figure 4. Of which the Poisson ratio of reclaimed concrete vcTake 0.2, W wire Poisson ratio vcTake 0.3.



(a) solid pattern (B) W wire thermal insulation board

Figure 4: Finite-element entity model

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3.3.2. Boundary conditions and the loads

The bending design of the wall panel applies the vertical concentrated load according to the three point points to form a pure bending section in the span. The design principle is as shown in Figure 5. The boundary conditions of the solid model are modeled at the bearing position; the load applies the uniform surface load within 200mm centered on the centralized load. The boundary conditions and loads are shown in Figure 6.

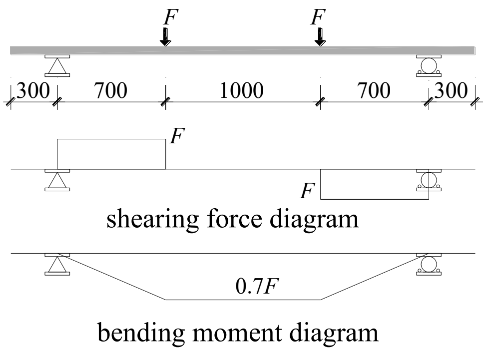

Figure 5: Schematic diagram of the bending design

Figure 6: Solid model boundary conditions and loads

3.4. Experiment Design

3.4.1. Test design and measuring point layout

Study the combined stress performance of wall board through wall board bending test. The wall board bending performance test device is shown in Figure 7, using three point loading to form a pure bend in the span.

Vertical monotonic loading, graded load level is determined according to the predicted value of cracking load and yield load, and the holding time of each load is not less than 5min.

The concrete strain measuring points are uniformly arranged on the bottom and both sides of the specimen, as shown in Figure 8; the reinforcement strain measuring points are set in the middle span, and the W wire is too thin to meet the patch requirements. Analysis of the stress of the steel wire in the sandwich panel by adding the optical circular reinforcement with a diameter of 6mm; the displacement meter is set on two supports and two sides of the span.

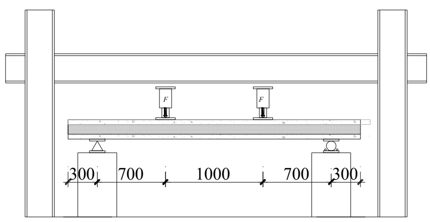

Figure 7: Test setup

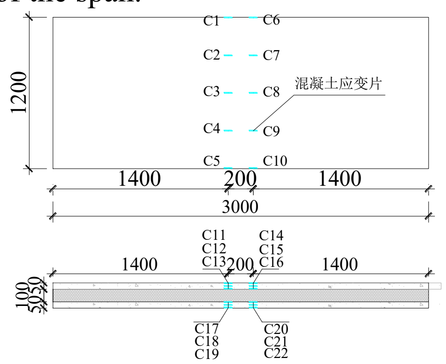

Figure 8: Arrangement of measuring points

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3.4.2. Description of the trial process

Due to the calculated bearing capacity of pure bending test is small, the dead weight of the distribution beam is 2 kN. Due to the initial defects of the production and processing problems, there are many dry shrinkage cracks on the side of the wall board. There are micro cracks on the side near the support, which extend to 200mm at the bottom of the board, but have little impact on the overall test results and test phenomenon. The test loading is shown in Figure Figure 9.

Figure 9: Test loading

Test loading level, the initial test level is 2 kN, loading to 6 kN, and then the loading level is 1 kN to load to the test piece to lose the bearing capacity.

Throughout the whole trial, Before the F = 8 kN, The specimen has no obvious phenomenon; At the time of F = 9 kN, Initial fracture penetration of the pure curved section, The crack width is 0.15mm; At F = 10 to 13 kN, As the load increases, The crack width gradually increases by 0.05mm, Plate bottom crack increased from 0.25mm to 0.4mm, Plate side crack increased from 0.35mm to 0.5mm, At the time of F = 14 kN, A new through crack is added at the bottom of the pure bend section, In the process, With the sound of the specimen damage, The bearing capacity has a downward trend; At F = 15 to 16 kN, The cracks have developed rapidly, The crack width increases more rapidly, New penetration crack width of 0.55mm; After 16 kN is directly loaded to the specimen to lose the bearing capacity, The maximum bearing capacity is 17.0kN, The process has an obvious sound of steel wire pulling.

3.5. Comparative analysis

3.5.1. Trial design was compared with the finite element analysis

The test specimen uses W wire diameter of 2.2mm, so the strain of the concrete thickness direction when the diameter of W wire is 2.2mm.

Figure 10 shows the concrete strain of the thickness direction of the test wall board when the vertical load is 8 kN. It can be seen from the figure, when the W wire diameter is 2.2mm, the sandwich insulation wall board cannot achieve the combined force.

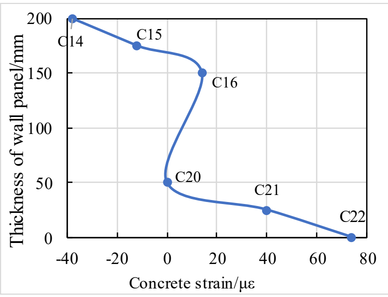

Figure 10: Solid model boundary conditions and loads

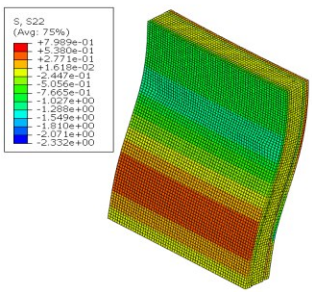

Figure 11: Test setup

Figure 11 shows the stress analysis of the thickness direction of the sandwich wall panel, and the strain of the recycled concrete is shown in Figure 16. From the finite element analysis results, it can be seen that when W wire is 2.2mm, the sandwich insulation wall board cannot realize the combined force of the wall board through W wire. Compared with the test results, the strain difference of the plate bottom concrete is not large, and the large output strain difference of 50mm may be due to the addition of 2 and full long reinforcing bars in the span of the side reinforcement strain of the test member.

4. Conclusion

(1) When the diameter of W wire is 2.2mm, the sandwich insulation wall board can not achieve the combined force, the wall board with higher bearing capacity requirements, need to be added with ordinary steel bars, or additional reinforced concrete trabecular or ribs.

(2) modules and their connections meet the specification requirements.

(3) The connection of the photovoltaic modules in the photovoltaic integrated wall panel is feasible and verified by the process test, and meets the requirements of safe and convenient production and construction.

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