Quality Control Measures for Building Structure Engineering Strengthening Techniques

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Abstract: This article investigates the quality management of building structure strengthening technologies through five aspects: technical management, materials, construction technology of strengthening layers, acceptance inspection and tracking, and quality assurance system. In technical management, stress on detailed design of the construction drawings as well as technical disclosure and dynamic adjustment. Material control encompasses incoming inspection, storage and compatibility verification. Bonding and anchoring processes are used to control construction technology. Acceptance inspection and monitoring are the criteria for process/final acceptance, long-term network monitoring. The quality assurance system includes the establishment of standardized operating procedures, personnel qualification management and quality responsibility tracing, which comprehensively improves the quality of strengthening projects.

1. Introduction

The strengthening of building structures involves a group of target technical measures to eliminate scope problems, consisting in the poor quality of load-bearing mechanisms and low durability due to design defects, mismanagement of construction or subsequent use, environmental degradation. The fundamental purpose is to rehabilitate or improve performance of the structure, applying technical and logical means for the enhancement of safety and serviceability. Quality control, as a crucial link in the strengthening project, is intertwined with the entire links of design, materials, construction and acceptance. It directly determines the reinforcement effect under load and its service life. This paper systematically elaborates the quality control measures for building structure strengthening technique from four aspects, including technical management, material control, construction technology and acceptance monitoring.

2. Quality Control in Technical Management

2.1 Detailed Design of Construction Drawings

Construction drawings are not only the most important carrier to transform technical requirements into physical entities, but also more detailed construction drawings can be obtained in practice, which can directly affect the quality of construction. Release of scientific research drawing should go beyond the traditional mode of annotation, establish a three-level annotation system consisting of "macro-layout – micro-construction – material parameters": for example, at the macro level, clarify the spatial layout and connection relationship between strengthening areas adjacent to surrounding components; at the micro level, provide details for key joint drawings (e.g., substrate removal depth /roughness control standards/cleanliness requirements for interface treatment); anchor systems require definitions such as parameters (material/specifications/layout spacing/embedment depth) and bonding methods with the original structure and cooperative working measures with strength layers; at the material parameter level, list in detail the performance indicators, brand ranges, and inspection requirements for strengthening materials such as structural adhesives, fiber composites, and steel, providing quantifiable technical basis for construction [1].

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2.2 Technical Disclosure and Dynamic Adjustment

Technical disclosure requires establishing a three-level disclosure mechanism of "general contractor – subcontractor – work team". Through drawing reviews, on-site demonstrations, video presentations, etc., systematically explain the operation process of strengthening techniques, key points of quality control, and safety protection measures, strengthening the quality awareness and operational skills of workers. Furthermore, a dynamic adjustment mechanism must be built. During construction, relying on equipment such as strain monitoring systems and crack observation instruments, collect structural response data in real-time. Combining construction progress and environmental changes, dynamically evaluate the strengthening effect and scheme deviations. When monitoring data exceeds warning values or significant changes occur in site conditions, promptly organize the design, construction, and supervision units for scheme optimization. By adjusting strengthening parameters, adding temporary supports, and other measures, ensure the technical scheme always remains highly adaptable to actual conditions, achieving quality control and safety assurance for the strengthening project.

3. Quality Control of Materials

3.1 Incoming Material Inspection and Storage

Incoming material inspection is the first line of defense for quality control and must strictly follow specification requirements for sampling and re-inspection. For bonding agents direct tension bond strength with the substrate must be tested as this is the most relevant indicator regarding cooperative working behavior of layer and matrix; for structural adhesives, process parameters such as pot life and curing time also have to be investigated. The indicators of the fiber materials, such as the mass per unit area, and the diameter of fibers, need to take sampling inspection; steel needs to test their mechanical properties and chemical composition. Both storage stage also need target measures based on the different characteristics of each kind of material: structural adhesives should be stored in dry cool condition without sunshine exposure (which will reduce performance), fiber materials should be stacked flat or rolled on up to avoid the folding induced mechanical performance loss, steel should be placed upon support and kept ventilated. Detailed complete-material record system: Ability to trace each batch of raw materials throughout its life cycle, including but not limited to production batch number, item specification level and test report number in corresponding records as well as the final use location of this material [2].

3.2 Material Compatibility Verification

The compatibility of the strengthening materials with the original structural materials is an important factor affecting the long-term durability of the strengthening system, and their compatibility must be verified in a systematic manner: for example, by determining the influence of pH value on changing condition, different treatment processes (sandblasting, pickling) to optimize surface roughness parameters on bond strength between various treatments; or by studying increasing bonding agents with significantly different coefficients of thermal expansion to assess cooperation through deformation coordination tests based on temperature changes or load effects during vibration under service loads. Also, think about electrochemical affinity (where metals will corrode faster in 1st contact with the difference of potential). The verification tests should be executed as close as possible to the working conditions in which it was proposed for execution, using the same lots of materials and construction processes provided for this project, since otherwise the test result will not represent its real condition. By verification of compatibility, potential risks can be identified in advance, material selection and structural design can also achieve the optimal solution of side by side to provide double protection for the years of use of reinforcement projects [3].

4. Quality Control of Strengthening Layer Construction Technology

4.1 Bonding Process

Structural adhesive preparation and application are central to the bonding process. Mechanical mixing: mechanical mixing using a low-speed mixer according to the ratio in the product manual, adjust the part of mixing time within 3-5 min so that obtains a uniform adhesive does not have color difference. Special roller or scraper should be used to ensure uniform thickness of the adhesive layer on the surface of substrate during application, preferably controlled in the range of 1.5–3.0 mm but not greater than that at risk cause sagging (if too thick), if too thin do not allow even after curing also bonding strength could be affected. For fiber materials, paste gradually from one end to the other applying a special roller repeatedly rolling to remove air bubbles and allow sufficient integration of adhesive into the fiber bundles. The rolling pressure needs to reach 0.1–0.2 MPa. For carbon fiber fabric, adopt a "three-coat application process" , namely applying a primer coat, laying the carbon fiber fabric, and then applying a top coat, ensuring the penetration depth of the adhesive layer is not less than 80% of the fabric thickness. The curing stage requires strict control of ambient temperature and humidity; when the temperature is below 5 ℃, heating measures are needed; when humidity is greater than 85%, ventilation must be enhanced [4].

4.2 Anchoring Process

Anchoring construction requires precise drilling as the foundation. Use diamond drill bits for mechanical drilling, with deviations in hole diameter, depth, and verticality controlled within ±1 mm, ±5 mm, and 1.5% respectively, ensuring effective embedding of the anchor in the substrate. After drilling, use high-pressure air to blow out dust from the hole, with blowing pressure not less than 0.6 MPa and repeated not less than 3 times. Check the cleanliness with endoscope or hole illumination equipment. Anchor agent injection uses a special injection gun: the filling process is carried out from the bottom to the top of the hole, so that there are no air bubbles remaining. As for the prestressed anchors, a dual-control indicator management should be selected, that is to say: real-time monitoring of the pressure force value through sensors and elongation measurement through displacement gauges. This means that the deviation between both must not be above ±5 % of the design value in order to prevent structural damage caused by excessive tensioning [5].

5. Quality Control in Acceptance and Monitoring

5.1 Process Acceptance Control

Process acceptance should specify an accepting system on the basis of "full-process coverage, multi-level control" for strengthening quality. As for concealed works such as anchor installation and interface treatment, 100% physical inspection of the all types performed must be adopted, video recording means high-definition camera will also be used to ensure that can retain full complex image data and provide traceability. For acceptance, you only need to check whether the diameter, depth, and verticality of holes for anchors are up to standard specification requirements; and whether the hole cleanliness meets the specification; as for substrate roughness (roughness) values after interface treatment such as moisture content (Moisture Content), a strict quantitative detection with special instruments is required which has no quantitative requirement in specifications, and then compared with various specification values. Phased load testing is required while constructing the strengthening layers. Confirm the cooperative deformation ability of reinforcement layer and original structure through simulating load effects under working conditions. The raw data of the measured test must be recorded on in real time, and it needs to be confirmed jointly by design units and supervision. In addition, other non-destructive testing of materials at geometric parameters (such as strengthening layer thickness and flatness) can be carried out using non-contact equipment: ultrasonic thickness gauges or laser scanners. The thickness deviation should control within ±5%, and the flatness error must not exceed 2mm/m so as to guarantee the construction accuracy of the strengthening layer [6].

5.2 Final Acceptance Standards

The final acceptance should be judged from three aspects: material performance, structure bearing capacity and appearance quality. For materials performance, secondary sampling inspection of specimens laid on-site with target-quality indicator values tested, need to be determined before construction including: tensile shear strength of structural adhesive; and the carbon fiber fabric ultimately needs to have a characterization of how much tensile strength it retains. The results of tests cannot be lower than 95% of the design value Static or dynamic load testing is necessary to complete the assessment of structural bearing capacity. The test load shall not less than 1.2 times of the design load with continuous cargo time no less than 2 hours. At this moment, meanwhile monitoring structural deformation crack development and strain response. The bearing capacity is acceptable only once the displacement increment is less than 0.05 mm/h and residual deformation rate is below 20%. Janome believes that appearance quality acceptance must be 0 drumming and defect free. Utilize percussion method with infrared thermography to detect lofting of the reinforcement layer, drumming area is ≤1% of total area 2. Visual inspection + crack width gauge measurement: the reinforcement layer is free from cracks, or if there are cracks, their law width is ≤0.05mm; surface flatness test (with a 2m straightedge), deviation≤3mm, no significant discoloration and peeling.

6. Construction of the Quality Assurance System

6.1 Standardized Operating Procedures

The key of quality assurance is standardized operating procedure, which needs to build the entire life cycle operational standard system for strengthening project. First, prepare the "Standardized Operation Manual for Structural Strengthening Engineering" national standards and industry experience combination. The manual includes 12 major processes such as material acceptance, interface treatment, strengthening layer construction, quality test and others. Each process offers a clear definition of operating steps, technical parameters, and acceptance criteria. In instance, in the phase of interface remedy, the policies stipulate quantifiable red flags such as concrete substratum extraction deepness ≥ 10mm, roughness Ra worth was regulated within 30–50 μm and also wetness information ≤ 4% with graphic summaries as well as errors instances evaluations. Secondly, realize electronic process inspection reporting through mobile APPs by carried out information management tools. However, after finishing each procedure, construction personnel shall upload operation photos and test data as well as self-inspection records. Supervisors review in real-time and use an electronic opinion signing to ensure a closed-loop process. Additionally, a video library for standardized operations can be established with 3D animation demonstrations and on-site practical operation videos of key processes (e.g. carbon fiber fabric pasting, anchor installation) made by the construction personnel for workers to learn at any time to reduce human operational deviations [7].

6.2 Personnel Qualification Management

Personnel qualification management is a key part of quality assurance, which has established the "qualification review - skills training - assessment certification" full-chain management system. Construction team selection: Verifying the enterprise's special engineering professional contracting qualifications, specifically verifying its performance capacity on similar projects in the last three years, technical equipment level and quality management system certification (the construction unit of construction has professional construction capacity). Create a Certification Required for Posting + Dynamic Assessment system for operator management. The skill training must be organized by provincial construction administrative departments and all employees involved in strengthening construction (such as structural adhesive preparation, carbon fiber fabric installation and anchor installation) are subject to this regulation. Only workers who have obtained the "Building Structure Strengthening Operation Qualification Certificate" can perform relevant work. Create an organizational annual mechanism re-training in the field of education on new materials, new processes and common- quality problems prevention and be therefore training hours are not less from 32 hours/year aiding. Also, foster a mentorship model for knowledge transfer, where senior technicians work on-site with new hires for 6 months to ensure they are adept at the basics of operation. Eliminate unlicensed operation and violation of rules by strictly controlling personnel qualification, and realize the improvement of construction quality from source [8].

6.3 Quality Responsibility Tracing

Quality responsibility tracing is a very effective way to strengthen quality control, which clarifies the need to build a complete closed loop of "responsibility clarification - responsibility fulfillment - accountability". Step 1: sign the "Quality Responsibility Letter" - at the beginning of each project, in order to clarify the quality responsibility boundaries between all parties (client, design, construction, supervision) and who is responsible for a specific position or person. Implement a "quality responsibility labeling" system during construction. Every time that an operator finishes any of these processes, they stick a QR code label on the physical piece. The code contains information on construction time, operator, test data, and acceptance records which denotes that one can read to quality behavior. For quality problems, implement a responsibility investigation mechanism immediately. Accurately focus the blame on responsible parties by reviewing construction records, surveillance videos, test reports and other documents. Graduated accountability approach, where the nature of economic sanctions will vary from suspension for training to a permanent ban depending on the severity of the violation. Imposing criminal responsibility according to law for acts causing more serious quality accidents.

7. Conclusion

Quality control of building structure engineering strengthening should be based on technical feasibility, guaranteed by material reliability, focus on construction accuracy and closed-loop monitoring verification. A full-chain quality control system of "design – materials – construction – acceptance" can be established, which is conducive to effectively improving the safety and service life of strengthening projects, and providing technical support for the renovation process as well as the functional upgrade of existing buildings. In the future, with the development and application of new materials and new processes, quality control for strengthening must continuously optimize standard systems and promote technological progress in the industry.

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