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Research Article

Discussion on solving cementitious grout for rebar sleeve splicing backflow problem during sleeve grouting based on TRIZ theory

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ABSTRACT

In response to the construction technical problem that the grout is prone to back flow during the grouting process of the steel sleeve grouting connection joint of the assembled integral concrete structure, the problem solving process is first analyzed using TRIZ theory, and then the creative solution is obtained using tools such as final ideal solution, causal analysis, resource analysis, contradiction analysis, physical field analysis, and innovative design software. Finally, the creative solution is evaluated and a series of simple and feasible solutions that are worth further research are proposed, such as expanding the grouting sleeve, placing the grouting material in a magnetic field in advance, ultrasonic vibration of the grouting material, and automatic sealing of the grouting opening. This provides ideas for solving the problem of slurry backflow, and also provides a reference for the application of TRIZ theory in the field of civil engineering.

Keywords: sleeve of rebar; grouting; TRIZ; cementitious grout backflow; prefabricated monolithic concrete building

1. Introduction

In recent years, the country has successively introduced relevant policies to vigorously promote the development of prefabricated buildings. The steel sleeve grouting connection is the most important and commonly used vertical connection method for assembling integral concrete structures. However, in practical operation, the quality of the joint is not satisfactory, and the grouting material at the sleeve connection is prone to insufficient filling. The reasons for this problem are multifaceted, but the problem of slurry reflux is often one of the important reasons for the insufficient filling of grouting material and insufficient connection strength at the sleeve connection. Domestic technical experts and scholars have also provided some solutions to the problem of slurry backflow during the grouting process of steel bar sleeves, mainly focusing on monitoring and improving the pressure output of grouting, improving construction operations, and controlling and managing construction quality [1-2]. These methods have some effect on reducing slurry backflow, but have not completely solved this problem. The existence of this problem will directly affect the safety, quality, and construction efficiency of assembled integral concrete structures.

TRIZ, also known as the Theory of Invention and Problem Solving, was a set of methods and theories for invention and problem-solving developed by Soviet scientist Genrich Archi Schuler and his disciples by analyzing a large number of patents in different fields. TRIZ, as a powerful tool for innovation and problem-

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solving, has become a part of the engineering culture of many world leading enterprises[3-5]. Therefore, we attempt to use TRIZ theory to solve technical problems in steel sleeve grouting construction, in order to obtain more efficient problem-solving solutions. TRIZ theory is widely applied in the field of mechanical engineering, but relatively less in the field of civil engineering. There are no relevant technical personnel or scholars in China who have applied TRIZ theory to solve the problems of prefabricated building construction. Therefore, this is a very worthwhile direction for research and exploration.

2. Technical problem-solving process

As shown in **Figure 1**, this process is also applicable to solving other technical problems in the field of civil engineering. In the application process, it is not necessary to strictly follow this process at every step. Several steps can be selected according to the specific situation, and the order of steps can be adjusted as long as an ideal solution can be found. Even if each step forms an immature and flawed solution, it can be recorded as a creative idea and further improved later.

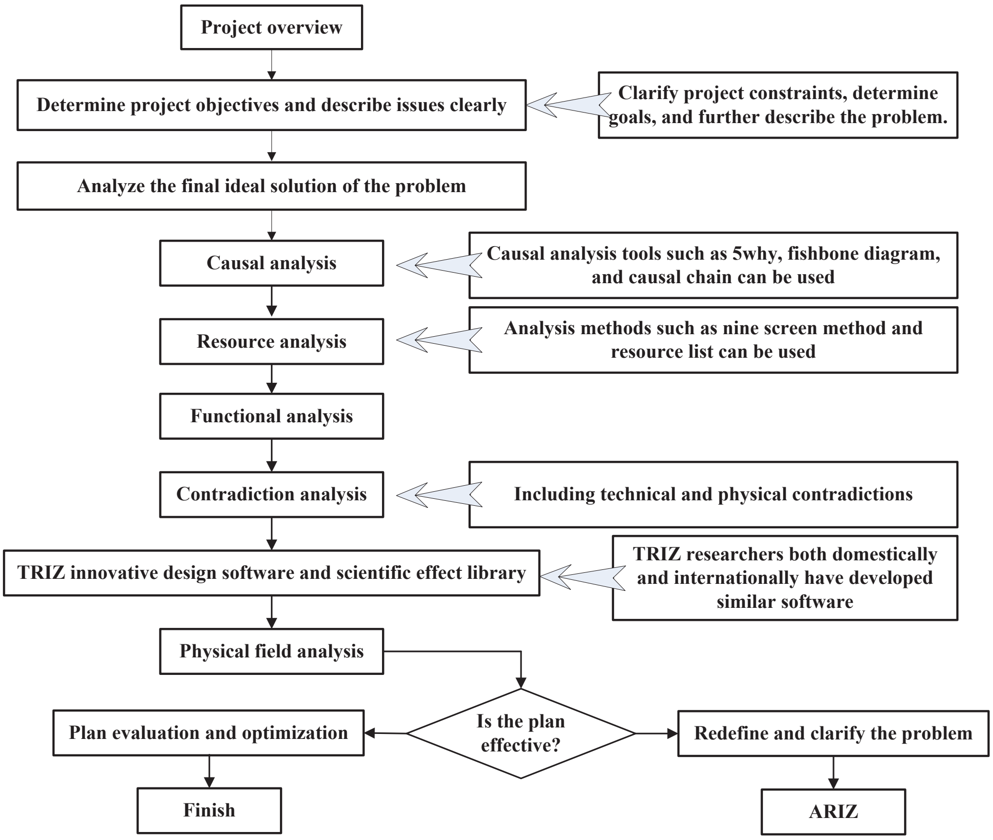

Figure 1. Technical problem solving flowchart.

3. Using TRIZ tools to solve construction technical difficulties

3.1. Project Overview of Slurry Backflow in Sleeve Grouting System

Taking the grouting connection of a prefabricated component sleeve as an example for research, the sleeve is a semi grouting sleeve. The materials and equipment used for grouting the entire sleeve are referred to as an engineering system. The design of this engineering system is to pre embed the sleeve in the upper prefabricated component, and one end of the sleeve is mechanically connected to the steel bars of the upper prefabricated component (usually threaded connection). The other end of the sleeve is a cavity, and the steel bars of the lower prefabricated component are inserted. Manual grouting guns or electric grouting pumps are used to inject grouting material from the sleeve grouting port into the connecting cavities and sleeve gaps of the upper and lower prefabricated components. The slurry first flows into the connecting gaps between the concrete of the upper and lower prefabricated components (commonly referred to as the connecting cavities), and then sequentially flows upwards into the gaps of each sleeve. After the slurry outlet is discharged, special rubber plugs are used to seal it [6-9].

3.2. Further description of project objectives and issues

Project objective: To reduce slurry backflow and improve the compactness of sleeve joint slurry filling.

The problem of slurry backflow occurs in the internal gaps and connecting cavities of the sleeve. The problematic joints are generally difficult to observe with the naked eye, and there is currently no good non-destructive testing method. Even if insufficient grouting is found, it is difficult to remedy.

3.3. Analyze the final ideal solution of the problem

The ideal vision of the solution is that it will not bring any other harmful effects (including keeping the entire system unchanged or becoming less complex), and the grouting material will automatically fill and compact in the gaps between the connecting cavity and the sleeve.

Creative solution 1: Provide technical training to construction personnel to proficiently master key construction techniques such as joint sealing, warehousing, grouting, and grouting mouth sealing around the connecting cavity. At the same time, pay attention to standardized operations and strict supervision and management.

Many experts and scholars have raised the issue of management operations, and from the perspective of TRIZ theory, this is a good way to improve the system without changing it.

3.4. Causal analysis

Using the causal chain analysis method, the deep-seated causes of the slurry reflux problem were analyzed, as shown in **Figure 2**.

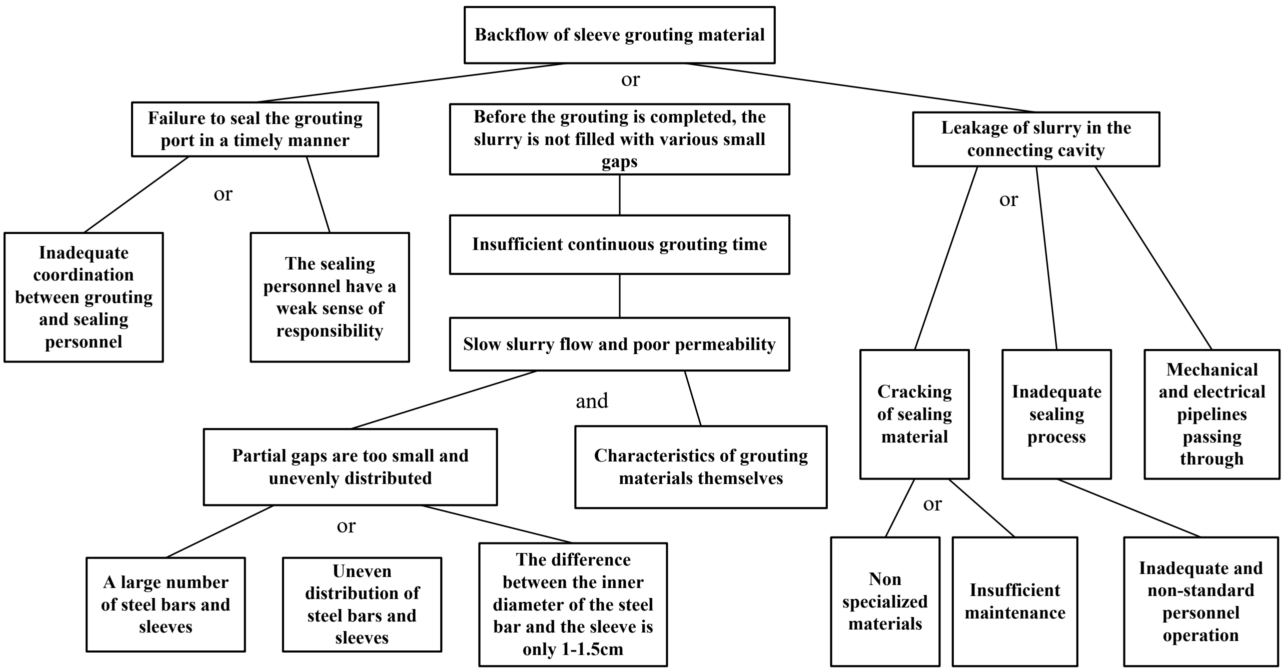

Figure 2. Causal chain analysis.

Creative solution 2: Adjust the composition of the grouting material, such as adjusting the proportion of admixtures such as water reducing agents and retarders, to improve the fluidity of the grouting material.

Creative solution 3: During the design phase, optimize the reinforcement of prefabricated components, while meeting the requirements of specifications and stress, and try to design them in small quantities, with large spacing and uniform distribution.

3.5. Resource analysis

Using the nine screen method to study the system, focusing on the existing problems, analyzing their input, output, past, present, future, causes, results, internal and external resource environment, in order to seek solutions.

Creative solution 4: In the production stage of prefabricated components, micro pressure sensors are embedded on the inner wall of the sleeve. If the sleeve grouting is full, the slurry will generate lateral pressure on the inner wall of the sleeve, which can be detected by the sensors.

3.6. Contradiction analysis

Transform the problem into a technical contradiction problem model, use the 48 × 48 contradiction matrix to find the corresponding invention principle, and obtain the creative solution, as shown in **Table 1**.

Table 1. Technical contradiction analysis.

Number	Problem description	Engineering parameters	Principle of Invention	Creative concepts
1	To increase the inner diameter of the grouting sleeve to facilitate the filling of grouting material, but it will reduce the thickness of the protective layer of prefabricated components and the clear distance between sleeves.	**Improved parameters:** volume of stationary object; **Deteriorating parameter:** structural stability.	40 , 35 , 31 , 34 ,30 ,2 ,5 , 28	According to principle 5 of invention: combination and merging **Creative solution 5:** Merge multiple sleeves and design them as connected expansion sleeves. One sleeve can connect 2 or more steel bars, and the bottom connection area of the sleeve is enlarged, which is not only conducive to grouting, but also easy to align the steel bars.
2	To improve the flowability and permeability of grouting materials, in order to increase the density of filling, but it will reduce the strength of the grouting material after solidification or make it prone to layering and bleeding.	**Improved parameters:** speed; **Deteriorating parameter:** intensity.	28 ,8 ,3 ,14 , 5 , 40 , 26	According to principle 8 of invention: weight compensation **Creative solution 6:** Raise the height of the grouting pump and perform pressure grouting. After all sleeves are sealed, no more pressure is applied. The grouting material continuously fills the gap between the connecting cavity and the sleeve using the kinetic energy generated by gravity potential energy, and maintains it for a few minutes.
3	To reduce the pumping pressure so that the grouting material can slowly fill the gap, but it will lead to inadequate pumping.	**Improved parameters:** pressure; **Deteriorating parameter:** reliability.	40 , 13 , 35 , 19 ,4 ,25 ,9 , 12 , 28	According to principle of invention 19: periodic action **Creative solution 7:** The hydraulic pressure output by the grouting pump varies periodically.

3.7. Using TRIZ innovative design software

Using the innovative foreign design software IWB, as shown in **Figure 3**, create a functional model based on the project description. The IWB software uses its built-in operators to provide prompts and generate creative problem-solving ideas.

In **Figure 3**, the arrow → represents the generation and cause, and the arrow with a short line → represents the reaction and obstruction. The green square represents the positive effect of the system, the red square represents the negative effect of the system, and the yellow square represents both positive and negative effects.

Creative solution 8: Add a substance with long linear molecules to the grouting material.

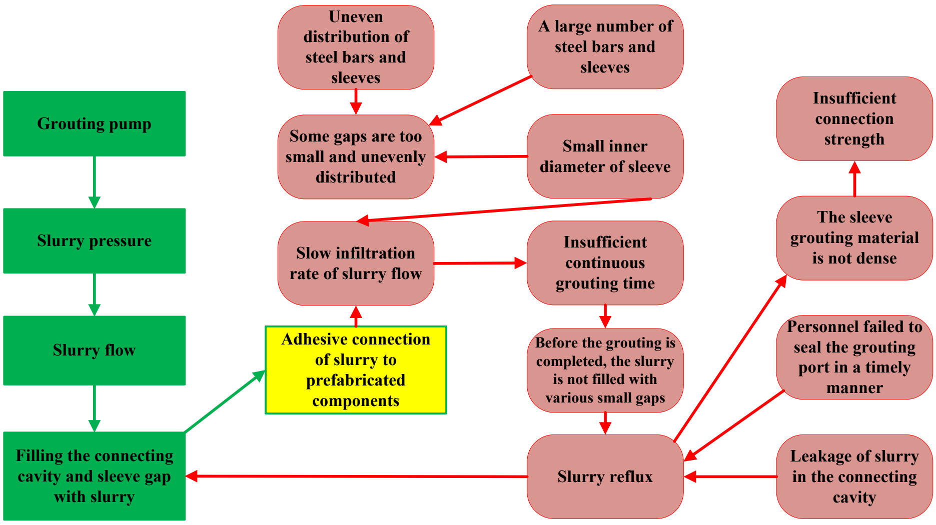

Figure 3. Functional model of innovative design software.

Creative solution 9: Design automatic sealing accessories, allowing grouting personnel to pull out the external interface of the grouting equipment while the grouting port can be self sealed.

Creative solution 10: Mix magnetic particles into the grouting material, introduce a vibrating electromagnetic field, and accelerate the flow and compaction of the grouting material.

Creative solution 11: Convert high-frequency electrical energy into mechanical vibration and emit it into the grouting material, which introduces a high-frequency ultrasonic vibration wave into the grouting material, producing "cavitation effect" or cavitation phenomenon, and improving the compactness of the grouting material filling.

Creative solution 12: Add charges to the inner wall of the connecting cavity and the surface of the metal sleeve, and add opposite charges to the grouting material, making it easier for the grouting material to fill into small gaps.

Creative solution 13: Extract air during the grouting process to improve the compactness of the grouting material.

Creative solution 14: Transform pressure grouting into pulse grouting, with the pulse rate consistent with the natural vibration frequency of the grouting material.

Creative solution 15: Before grouting, place the grouting material in a magnetic field for better fluidity, easier filling into the sleeve gap, and faster hardening and earlier strength. Magnetic field effects can be controlled by generating magnetic field pulses.

3.8. Field analysis

As shown in **Figure 4**, for an insufficient physical field model, the standard solution 29 is transformed into a complex ferromagnetic field model and the standard solution 35 applies current to generate a magnetic field.

Creative solution 16: Use electromagnetic fields to activate water to accompany grouting materials, improving their fluidity and strength.

Creative solution 17: Adding magnetostrictive materials to the grout will change its shape when a magnetic field is applied, thereby using the magnetic field to control the vibration or movement of the grout and improve the filling effect of the grout.

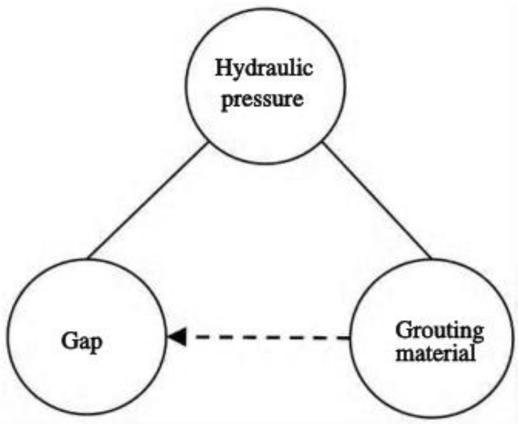

Figure 4. Material Field Model - Grouting Material Filling.

3.9. Creative solution evaluation and optimization

We will categorize the creative solutions we have obtained into the following categories: improvement of silt irrigation slurry; Improvement of grouting sleeve; Improving the working mode of grouting equipment for the bowl; Pre treatment of the sleeve by Yu; Yu Construction Quality Control and Management; Foolish design optimization. By using the impact effort matrix diagram method [5] for analysis, considering both economic and technical difficulties, creative solution 1, creative solution 4, creative solution 5, creative solution 8, creative solution 9, creative solution 11, creative solution 12, creative solution 14, and creative solution 17 have a relatively good effect on solving this problem.

3.10. Problem solutions

3.10.1. A relatively simple and feasible solution to the problem of sleeve grouting backflow

Under the premise of emphasizing construction quality management and design optimization, relatively simple and feasible solutions can be adopted, such as expanding the grouting sleeve, placing the grouting material in the magnetic field in advance, automatically sealing the grouting mouth, and ultrasonic vibration.

(1) Grout expansion sleeve

As shown in **Figures 5 and 6**, in prefabricated shear walls and columns, multiple sleeves are combined and designed as connected expansion sleeves. One sleeve can connect 2 or more steel bars, and the space is large. The slurry is easy to fill and compact, and the steel bars are also easy to align. Expanding the middle of the sleeve with arc-shaped transverse ribs to increase anchoring. There are positioning protrusions at the ends to help align the steel bars.

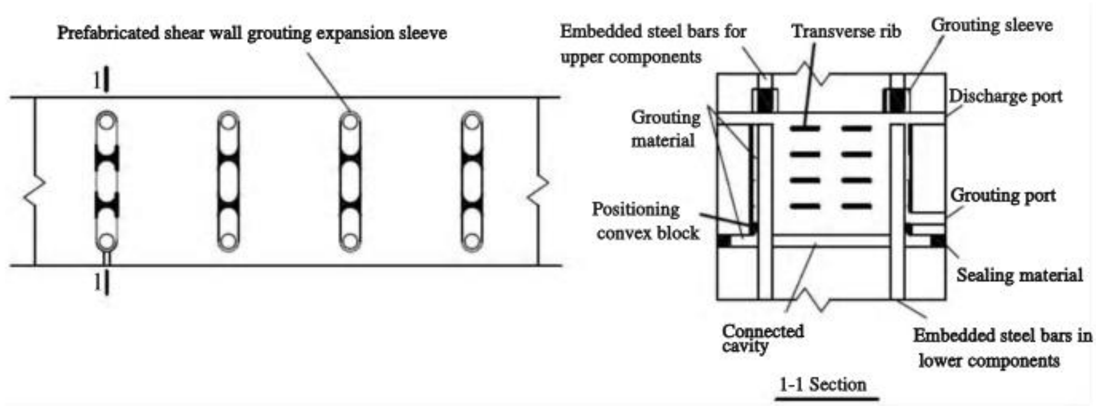

Figure 5. Grouting expansion sleeve for prefabricated shear walls.

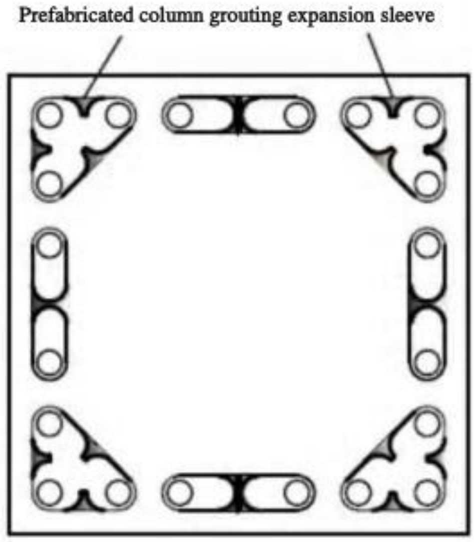

Figure 6. Expansion sleeve for precast column grouting.

(2) The grouting material is placed in the magnetic field in advance

As shown in **Figure 7**, before grouting, the grouting material is placed in a magnetic field, which improves its fluidity, makes it easier to fill the sleeve gap, and has fast hardening and early strength. A coil that can generate a magnetic field can be added at the rear end of the grouting nozzle to magnetize the grouting material.

Figure 7. Pre placement of grouting material in a magnetic field.

(3) Automatically seal the grouting port

As shown in **Figure 8**, the accessory that automatically seals the grouting port can self seal the grouting port while the grouting personnel pull out the external interface of the grouting equipment. The excess slurry inside the accessory can be removed later.

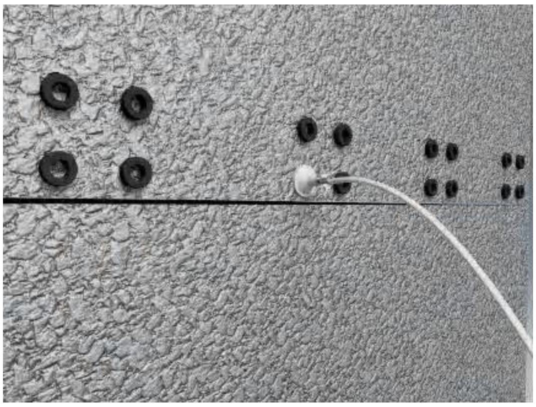

Figure 8. Automatic sealing grouting port accessories.

(4) Insert the ultrasonic vibration rod into the grouting material

As shown in **Figures 9** and **10**, the plug that blocks the discharge port is combined with an ultrasonic vibration rod, inserted into the grouting material, and ultrasonic vibration waves are introduced into the grouting material to improve the compactness of the grouting material filling.

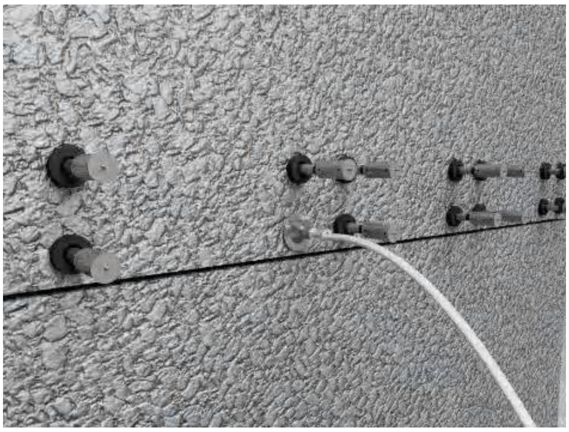

Figure 9. Insertion of ultrasonic vibration rod into grouting material.

Figure 10. Ultrasonic vibration rod.

3.10.2. Creative conceptual solutions worth further research

(1) Add a substance with long linear molecules to the grouting material.

(2) To convert pressure grouting into pulse grouting, the pulse rate is consistent with the natural vibration frequency of the grouting material.

(3) Add charges to the inner wall of the connecting cavity and the surface of the metal sleeve, and add opposite charges to the grouting material, making it easier for the grouting material to fill into small gaps.

(4) Adding magnetostrictive materials to the grout will change its shape when a magnetic field is applied, thereby utilizing the magnetic field to control the vibration or movement of the grout and improve the filling effect of the grout.

4. Conclusion

This article applies the TRIZ innovative method based on the problem-solving process, proposing that, under the premise of emphasizing construction quality and design optimization, relatively simple and feasible solutions such as expanding the grouting sleeve, placing the grouting material in the magnetic field in advance, ultrasonic vibration grouting material, and automatic sealing of the grouting mouth can be used to solve the problem of slurry backflow. At the same time, conceptual schemes worth further research, such as adding long linear substances, pulse grouting, adding opposite charges, and magnetic field controlled grouting, were also proposed. The solution to the problem of grouting sleeve slurry backflow has been expanded, providing basic information and technical references for the solution of this problem.

The reasons for the insufficient slurry inside the sleeve during the grouting process are not only due to the backflow of the slurry, but also due to other reasons. For example, the inserted steel bars are not centered in the sleeve, but are biased to one side or even attached to the inner wall of the sleeve, seriously affecting the grouting effect. This issue of steel bar positioning is also quite prominent. For this type of problem, we can still consider using TRIZ theory to seek solutions in the future. The TRIZ method is a very powerful tool for innovation and problem-solving. Applying and promoting this method to solve the problems in the design, production, and construction of prefabricated buildings will play a good promoting role in the development of prefabricated buildings in China.

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