Analysis on the causes and prevention measures of the potential safety hazard of the formwork support system

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Abstract. In recent years, with the rapid development of urban modernization, the collapse of formwork support system occurs frequently. The erection of formwork support system has become the key control object in the current construction safety production. This paper summarizes the main reasons for the potential safety hazards of the formwork support system in four aspects. The design of formwork support scheme is lack of guidance; the material and specification of formwork support system do not meet the standard; the formwork erection personnel are not professional; the management concept of the general contractor and subcontractor is different, and the supervision implementation is not complete. In view of the above reasons for the potential safety hazards, this paper innovatively puts forward the use of three-dimensional virtualization technology to make the virtual positioning of the mold support system, increase the mold support system process (three-dimensional positioning, solid line inspection); the frame rental is suggested to be self-sufficient, customized frame materials to establish the internal material catalogue for the use of turnover; sets up a new type of work, carry out assessment and training according to the scaffolders, and understand woodworking skills, so as to promote the standard erection of formwork support system; changes the conventional quota calculation rules, and increases the lower limit usage amount (tonnage calculation) of support system materials per square meter in the subcontract management agreement, so as to limit the abuse of excessive cost control.

1. Introduction
Formwork support is an indispensable part in the construction of cast-in-place concrete buildings. With the diversification of architectural design and the rapid development of infrastructure, the safety accidents of formwork support system occur frequently. The safety accidents of formwork support system have caused immeasurable economic losses to the country, and some even have a very bad impact on the society. Therefore, the safety of formwork support system is not only highly valued by the construction industry, but also listed as the key hidden danger investigation project in the construction process. How to avoid or reduce the safety accidents in the construction of formwork support system is the concern of every construction workers.

Taking 60 collapse accidents of formwork support system in recent years as examples, Li M et al. (2010) made statistics and analysis on the causes of the collapse of formwork support system and summarized the rules of the accidents. Chen A et al. (2008) summarized the causes of the collapse accident of the fastener type steel pipe high formwork system in recent years, and expounded the technical prevention and control measures for the causes of the accident. Wu Y et al. (2011) cited four collapse accidents of fastener type steel tube high formwork support structure, studied the collapse...
failure mechanism of formwork support structure, summarized the causes of the overall collapse of the high formwork support structure, and proposed the countermeasures to prevent the overall collapse of the high formwork support structure. According to the field investigation and detection of collapse accident of high support formwork, Li D et al. (2011) analyzed the stability of formwork system. Song Z (2016) summarized the existing problems of formwork support and the experience of collapse accident, and put forward the safety precautions. Based on the practical problems and related cases in the project, Fu G (2017) analyzed the main problems that should be paid attention to in the application of steel tube fastener support system in the high formwork support.

Different from previous studies, based on the construction experience in recent years, through observation and research, combined with the experience of investigation and observation and learning, this paper summarizes several main reasons for the potential safety hazards of formwork support system, and put forward innovative solutions and suggestions for the reference and research of engineering technicians or peers, to achieve the purpose of reducing or eliminating the potential safety hazards in the formwork system during construction.

2. Concept of "formwork support system" and "potential safety hazard"

2.1. Concept of "formwork support system"

The formwork support system (see figure 1) that we usually define and understand includes vertical component support and horizontal component support. Its function is to strengthen the overall spatial stiffness and stability of the structure through the establishment of its own structural system, so as to overcome the global and local instability under the load. During the construction process, it mainly transmits the vertical static load of the components, the dynamic load generated by the personnel and machinery during the construction process and the horizontal wind load generated by the natural environment.

Figure 1. Diagram of formwork support system

2.2. Concept of "potential safety hazard"

In the process of construction and production, due to unsafe behaviors of people (such as management ability, system implementation, operation skills, psychological state, knowledge level, physiological function, etc.), unsafe conditions of objects (such as aging and rusting of formwork materials, removal and displacement of supporting members), and environmental impact (such as severe weather such as rain, snow, strong wind, etc.), there will be a variety of problems, defects, faults, symptoms, hidden dangers, etc. If not be found or eliminated, these unsafe factors will disturb and affect the normal production process or social activities. Some of these unsafe factors are defects and shortcomings. As long as defects are eliminated after inspection, problems can be solved, and conditions for potential stimulation will not be generated; some of them have conditions for potential stimulation, and
potential safety hazard will be generated. Without rectification or effective safety measures, accidents are likely to occur.

3. The effect of potential safety hazard in formwork support system
The potential safety hazard of formwork support system is accidental, potential, causal and multiple. In the process of construction and production, due to the joint action of unsafe behavior of people, unsafe state of objects, diversification of environment and other factors, the technical scheme lacks guidance, the construction implementation is not in place, the quality and specification of materials are difficult to control, the daily supervision task is heavy, which indirectly restricts the development of engineering construction.

4. The analysis of potential safety hazard in formwork support system
Based on the typical accident cases and work cases of formwork support, combined with the five influencing factors (person, machine, material, method and environment) of the comprehensive quality management theory, this paper analyzed the causes of the potential safety hazard of formwork support deeply.

4.1. Typical safety accident cases of formwork support system
Case 1: On June 11, 2010, the formwork of Qilin guild hall collapsed in Wuling mountain villa, Miyun County, Beijing.

Cause analysis: The scheme has no pertinence; the frame structure lacks the connection with the structure; the supervision and management is missing; the beam, slab and column concrete are poured at the same time; the main supporting materials are unqualified, etc.

Case 2: On December 31, 2012, the formwork of Jinqiao parking lot project of Shanghai Metro Line 12 collapsed.

Cause analysis: There are serious defects in the formwork support system, the actual steel pipe and fastener materials deviate from the requirements of the scheme, the distance between the poles is too large; the supervision procedure is missing; in order to rush to work, the beam, slab and column concrete are poured at the same time.

Case 3: On January 6, 2013, the formwork of production experiment building and comprehensive office building project of Huadian (Beijing) Thermal Power Co., Ltd. collapsed.

Cause analysis: The concrete of beams, plates and columns shall be poured at the same time; the main supporting materials are unqualified; the diagonal bracing and wall connecting parts are missing; the supervision and management are missing.

4.2. Induction of safety accident cases through quality management elements
Based on the analysis of the above typical accident cases and the summary of quality management elements, it is found that there are common reasons for the three safety accidents, that is, the main factors causing the safety accidents are human factors (too large spacing of poles, not set up the diagonal bracing wall pieces according to the plan), and the material factors (the main supporting materials are unqualified), construction method (the scheme is not targeted and separated from the actual environment), construction environment (blind pursuit of construction period, weak safety awareness), etc. Based on the lessons of safety accidents of formwork support system over the years, the causes of relevant accidents in four aspects were summed up, namely: the design of formwork support scheme is lack of guidance, virtual layout is not carried out according to the actual situation, dead angle is set up on site, and the scaffold cannot be set up, which makes the scheme form a blind spot in the implementation; the material and specification of formwork support system do not meet the standard, the market rental materials do not meet the standard requirements, and the calculation of scaffold system is derailed from the actual situation; the formwork erection personnel are not professional, and are generally non-professional carpenters, with uneven quality; the management concept of the general contractor and subcontractor is different, the cost calculation rules of the
formwork support system are too general, the cost and profit conflict, and the supervision implementation is not complete.

4.3. Analysis of potential safety hazard of formwork support system in engineering cases

Here, by referring to the statistical data of "types of potential safety hazards existing in the formwork support system" made by the QC group I participated in the project, several main reasons for potential safety hazards existing in the formwork support system can be identified, as shown in table 1 and figure 2.

Table 1. Analysis and statistics of potential safety hazards of formwork support system in several project

| No. | Types of potential safety hazards                                    | Number | frequency | Cumulative frequency |
|-----|---------------------------------------------------------------------|--------|-----------|----------------------|
| 1   | The non-standard arrangement spacing of the frame members in the room| 45     | 40%       | 35%                  |
| 2   | Fastener loosening, rod non-compliance, free end length exceeding the standard | 20     | 18%       | 58%                  |
| 3   | The insufficient quantity of diagonal bracing and wall connecting parts | 17     | 15%       | 73%                  |
| 4   | The material of formwork support system not meeting the requirements | 14     | 12%       | 85%                  |
| 5   | Inadequate safety supervision                                       | 11     | 10%       | 95%                  |
| 6   | Other reasons                                                       | 6      | 5%        | 100%                 |
|     | Total                                                               | 113    | 100%      | 100%                 |

Note: The number of abscissa corresponds to the number in table 1

Figure 2. Cumulative frequency curve of potential safety hazards of formwork support system

4.3.1. Analysis of the reasons for the non-standard arrangement spacing of the frame members in the room. The scheme is lack of pertinence and guidance: with the development of building diversity, many buildings are magnificent in appearance and different in interior space modeling. The technical scheme of formwork support is lack of pertinence in the design of heterosexual structures, and most of them are uniform or even directly applied, as a result, the spacing of the supporting members of the mold base is not standardized, and the dead angle of some rooms is not supported, the technical scheme of formwork support is not prepared according to the actual situation on site, and lacks pertinence and guidance. The difference between the calculation diagram in the scheme and the
construction site is too large, and the theory is divorced from the practice, which cannot guide the construction accurately.

There is randomness in erecting the support frame by the construction personnel: according to the technical scheme of formwork support, the rigidity and stability of the frame are checked according to the structural static load and the construction live load, although the safety factor is improved in the calculation process, due to the lack of safety and quality awareness and randomness of the workers on site, the distance between the poles is often too large, which seriously deviates from the technical scheme and affects the safety of the formwork system.

4.3.2. Analysis on the causes of fastener loosening, rod non-compliance, free end length exceeding the standard. The formwork erection personnel are not professional, and their skills are uneven: generally, the formwork support system is set up by carpenter at the construction site, but the carpenter does not have the hand feeling for fastening, does not form the system concept for the formwork support system, and lack of safety awareness for the erection of the scaffold in mechanical construction, which often leads to the fastening of the system parts is not firm, and the tightening torque does not meet the requirements. At the same time, in the second check process of the formwork system, only the elevation of the formwork and the sealing of the board surface are concerned, and the integrity and stability of the formwork support system are ignored. Even for the convenience of the second check, the scaffold body is removed and changed at will in the process. Due to the lack of specialized system skill training, the above unsafe behaviors will lead to serious safety risks.

Aging and worn-out materials are not replaced in time: during the construction process, due to the long-term use and repeated turnover and handling of support frame materials, serious aging, metal fatigue, bending deformation, damage and obsolescence occur. The project did not replace the old support frame materials in time, and the aged and deformed materials were still used on site to set up the support system, which resulted in the phenomenon that the fasteners could not be fastened, the vertical bar was bent, etc., which seriously deviated from the theoretical value of the scheme. Therefore, because of the unsafe state of objects, there are serious security risks.

The control of free end length is not in place: according to the critical force of member stability, it is related to the material of compression bar, the section shape and size of compression bar, the length of compression bar and the support of compression bar. The critical force of the stability of the member is inversely proportional to the length of the compression member, and the support connection mode of the compression member determines the slenderness ratio of the member. Therefore, if the length of the free section of the formwork support system is not controlled in place, it will seriously affect the stability of the support system, resulting in the instability of the frame.

4.3.3. Analysis of the reasons for the insufficient quantity of diagonal bracing and wall connecting parts. The layout of diagonal bracing and wall connecting parts is directly related to the overall stability of the frame. The frame failure is the overall overturning failure, and the horizontal and vertical diagonal bracing and wall connecting parts are usually not constrained in the scope of failure area. Therefore, the reasonable setting of diagonal bracing and wall connecting parts is the key point of formwork safety. Therefore, the reasonable setting of diagonal bracing and wall connecting parts is the key point of formwork safety. In the construction process, because the formwork quota is calculated according to the building area, the objective concept of the subcontractor and the general contractor is different. Generally, the general contractor considers the whole site safety goal, while the subcontractor mixes the concept of cost control with the implementation of safety goal due to the uneven quality, which directly leads to the less quantity of leased pipes used in the erection of formwork support system compared with the specified quantity of formwork scheme.

4.3.4. Analysis of the reasons for the material of formwork support system not meeting the requirements. The calculation results of member stability depend on many factors such as material strength, moment of inertia, section area, member length, load and so on. There is no problem in the
general scheme according to the standard member model of the code, but the steel pipe material on the
market does not meet the model of Ф 48.3 × 3.6 according to the industry standard, generally, the wall
thickness of steel pipe is about 3mm. Even with the price competition in the rental market in recent
years, there are seriously illegal reducing steel pipes on the market, which directly reduces the moment
of inertia and strength of steel pipes. Generally, the external diameter of adjustable supporting screw is
32mm, which cannot meet the requirements of the specification that the external diameter should not
be less than 36mm, which makes the site formwork support system seriously deviate from the basic
requirements of the scheme design. Therefore, the accident occurs.

4.3.5. Analysis on the causes of inadequate safety supervision. Safety supervision is the last insurance
to ensure the safety of formwork support system. Due to the uneven quality of management personnel,
weak awareness of safety management, and construction management focusing on cost and duration
control, the implementation of safety system is not thorough, safety education is formalized, process
inspection and acceptance are not in place, which indirectly leads to the loss of the last insurance of
formwork support system. As a result, potential safety hazards develop into safety accidents.

5. Prevention and control measures for potential safety hazards of formwork support

Based on the above analysis of the causes of the potential safety hazards of the formwork support
system, through summary and classification, and starting from the fundamental point of the problem,
the targeted prevention and control measures are determined: First, do a good job in technology,
optimize the technical scheme of formwork support, simulate and deepen the guiding positioning
drawing of formwork support system. Then make the virtual positioning of formwork in the building
in combination with the drawing, through virtual observation, check whether the support system meets
the feasibility of construction positioning. Before erecting the scaffold, add the fixed-point setting out
process and conduct the line inspection. Second, the material control of the support frame should be
done to ensure that the frame material and member specifications are consistent with the basic data of
bearing capacity calculation of the support system. Third, do a good job in the professional training of
the formwork system erection personnel, conduct the training and assessment of the carpenters who
set up the formwork system in accordance with the requirements of the scaffolders, set up professional
formwork erection workers, set posts and responsibilities, strengthen the supervision and management
of the daily formwork, and formulate the management system of the general contractor and
subcontractors.

5.1. Prevention and control measures for lack of pertinence and guidance

5.1.1. Checking calculation of formwork support system based on the actual situation of the site.
According to the above analysis, due to the variable construction environment, the checking
calculation of formwork is usually a pure vertical stress system, while the actual stress on site is the
combined effect of horizontal load and vertical load, and the load size is random. For example, the
spreading thrust during concrete pouring, wind load, horizontal thrust when lifting objects fall on the
formwork, and reaction force when people walk will affect the stability of the scaffold to generate
horizontal overturning force. Therefore, in the scheme design stage, in addition to the vertical load
accumulation checking calculation, the comprehensive action with horizontal load shall be considered
in all aspects, and the internal force combination shall be carried out. In the application of the
calculation software, the most adverse effect of the support frame should be considered, so as to adjust
the foundation parameters of horizontal force properly, and make the calculation environment of the
support formwork close to the actual situation to the maximum extent.

5.1.2. Deepen the positioning of formwork support system with guidance. In the structural construction
stage, the formwork support scheme shall be designed according to the checking calculation results of
the formwork support system, combined with the detailed characteristics of the room to deepen the
detailed positioning layout of the formwork support members with guidance. It makes the position, size and relationship of each member of the formwork support system clear at a glance. During the preparation of the scheme, it avoids the conflict between the position of members and the structural entity, and overlaps with itself, and fully maps the theoretical model of the calculation of the formwork support scheme to the actual formwork erection process, use virtualization technology (see figure 3) to make visual preview, avoid dead angle of erection, increase erection process of scaffold, virtual positioning before erection, and set up support system after site positioning and line inspection, so as to standardize the formwork support system in the erection process, and make the formwork support system accurate during construction.

Figure 3. Virtual positioning 3D view

5.1.3. The basic data should be combined with the actual situation in scheme modeling and calculation. Due to the fierce competition in the rental market, most manufacturers start from the material itself to reduce the material quality. In the rental market, the wall thickness of supporting pipes is difficult to meet the specification requirement of \( \Phi 48.3 \times 3.6 \), most of which are 3.0-3.2mm, and even the wall thickness of some pipes is only about 2.8mm. The materials such as the external diameter of the adjustable supporting screw, the thickness of the supporting plate, the cross-sectional dimension of the supporting wooden keel, and the quality of the fastener are all lower than the requirements of the specification, which directly leads to the calculation in accordance with the material standards specified in the specification in the process of scheme modeling and calculation, which will lead to the serious base value error and the potential safety hazard of the supporting system. Therefore, in the process of modeling and calculation, it is necessary to check the formwork supporting materials such as the process formwork pipe, U-bracket, keel and fastener in advance, take the minimum standard of the site supporting pipe for checking calculation, ensure that the scaffold material and member specification are consistent with the basic data of the bearing capacity checking calculation of the support system, improve the safety reserve coefficient, and avoid the potential safety hazards caused by the wrong selection of the scheme modeling base.

5.2. Prevention and control measures for support frame materials not up to standard
The quality of formwork support system materials shall be strictly controlled, and the wall thickness, model and specification of pipes, fasteners, u brackets and keels shall be inspected, so as to avoid the fake and inferior products with necking of members, too thin wall thickness and too small section size mixed into the construction site, and strive to establish the self-renting and self-supplying mode. The support frame pipes and accessories shall be customized according to the specification requirements, and the manufacturer shall directly supply the support system steel pipes, and establish the account for rental and use of turnover materials and tools, track and keep the support pipes in the whole process, so as to ensure the turnover and use of qualified materials. Starting from the material quality itself, it can eliminate the potential safety hazards brought by the material itself.
5.3. Prevention and control measures for non-professional post setting and uneven quality of formwork support system erection personnel

5.3.1. Strengthen the training of professional personnel, create new types of work and be familiar with the skills of scaffolder and carpenter. In order to avoid the potential safety accidents caused by the erecting personnel of the support frame, the support system shall be constructed and erected according to the formwork scheme by the professional workers who are familiar with the professional scaffolders and woodworking skills. During the whole process of erecting the support frame and the second review, the new professional workers shall operate. After the erecting of the support formwork system is completed, the carpenter shall install the formwork. For the new type of work of erecting formwork support system, scaffolder skills, carpentry skills, safety education and training, and technical quality supervision should be carried out regularly, so as to ensure the safety of formwork support system and improve the erecting efficiency of formwork support system.

Strengthen the supervision and management of formwork erection. The formwork support system shall be supervised and managed by three measures, namely, pre prevention, in process control and post inspection. First of all, pay attention to determine whether the erector's understanding of the formwork support design scheme is correct, then supervise whether the formwork support system meets the requirements of the scheme during the erection process, and finally check whether the integrity, detail nodes and elevation of the formwork support system meet the standard.

Pre preventive measures shall be taken in advance to ensure that the erecting workers can accurately understand the design intention of the formwork support scheme, understand the key points of the support system. Pass the requirements of the formwork design scheme to the erecter to control the quality of the formwork body from the source of the formwork support system and eliminate the potential human safety hazards.

In process control ensures that in the process of erecting the support frame, the deviation between the formwork system and the formwork support scheme caused by human factors can be found in time, and the causes of the deviation are analyzed to develop a targeted correction scheme. Through the comparison and discussion of the schemes, the best scheme shall be implemented, and the rectification shall be carried out in time from the initial stage of the deviation of the formwork support system, so as to avoid the phenomenon of large-scale rectification due to the non-compliance of the scaffold with the specifications and scheme requirements after the erection. Minimize the huge waste of human and material resources.

Post inspection is the last guarantee to ensure the safety of formwork support system. For the completed support frame, it is important to check whether the free end value of the member exceeds the standard, whether the setting of the bottom bar, cross brace and wall connecting member is set according to the specification, whether the distance between the vertical bars and the step distance between the horizontal bars meet the requirements of the scheme, and whether the elevation of the frame meets the design requirements. During the construction of other processes on the formwork support system, it shall be avoided that the material stacking load exceeds the bearing range of the formwork support design. It is strictly prohibited to stack materials in a centralized way, so as to reduce the disturbance of machinery and personnel to the scaffold and ensure the safety of formwork support system.

5.4. Prevention and control measures for inconsistent management concepts of general contractor and subcontractor

As we all know, the human factor is the most important one. The foundation of project construction is labor subcontracting, the main management body is construction general contracting, and the field management mode is joint management of general contracting and subcontracting. The general contractor shall not only require superficial but also substantive communication with subcontractors. With the development of modern architecture, the combination of human safety awareness and management concept is becoming more and more diversified. The goal concept of the general
contractor and the subcontractor is different. The focus of construction safety and management cost always fluctuates. Generally, the general contractor considers the whole field safety goal, while the subcontractor inputs the concept of cost goal at the same time of implementing the safety goal due to the uneven quality, which deviates from the plan requirements from the management. These will become the weak link of the general subcontract management, which will easily lead to the security risks of the formwork support system. By taking effective management measures of general contracting and subcontracting can we avoid potential safety hazards.

5.4.1. Develop and assess the management system of general contracting and subcontracting. According to the actual situation of the construction site, a targeted general subcontract management system shall be formulated systematically, the management objectives shall be unified, the subcontract management awareness shall be improved, and the management attitude shall be standardized. Through the implementation of the system, the unsafe behaviors of people in the construction process are minimized. According to the pre-determined evaluation criteria, the assessment is carried out, and the deviation of general contracting and subcontracting management is constantly sought for correction. In the process of correction, a more optimized and feasible management system of general contracting and subcontracting is selected, step by step.

5.4.2. Change the cost calculation rules of the conventional formwork support system. According to the actual situation of the construction site, when the quota of formwork is calculated according to the building area, it is suggested to add the number of formwork members or the lower limit of tonnage, this will economically motivate the subcontracting team, increase the enthusiasm of the construction of the subcontracting team, make the subcontracting team essentially implement the quality objectives, safety objectives and cost objectives of the project, and then unify the management concepts of the general contracting and subcontracting to eliminate the potential safety hazards.

6. Conclusion

There are many reasons for the potential safety hazards of formwork support system, but the basic reasons are roughly divided into four aspects: the design of formwork support scheme is not instructive, and there are blind spots in the implementation of the scheme; the materials and specifications of the materials used in the formwork support system do not meet the standard; the quality of formwork erection personnel is not professional and uneven; the management concepts of the general contractor and the subcontractor are different, and the implementation of supervision is incomplete.

In the prevention and control of the potential safety hazards of formwork safety, the principle of "prevention first, combination of prevention and control" should be followed; the basic principle is to standardize the technical scheme of formwork, to ensure the pertinence and guidance of the scheme, to ensure the feasibility of the construction technology of formwork support system; to improve the material quality of formwork support system, to improve the safety reserve of formwork support system; to strengthen the quality of formwork erection personnel to avoid unnecessary safety hazards caused by unsafe behaviors of people; aim at unifying the management concepts of general contracting and subcontracting, reduce or eliminate management differences, achieve mutual benefit and win-win results, fundamentally eliminate unsafe behaviors and strengthen safety awareness.

This paper cannot discuss all the potential safety hazards of the formwork support system, but after mastering the general factors that cause the potential safety hazards, we should strictly control the procedures in the aspects of scheme design, personnel construction, material selection, management system, etc., so as to strictly control the procedures and responsibility to individuals. Before the commencement of construction, the targeted prevention and control measures or plans shall be prepared, and after joint review and discussion, the construction parties shall be organized to strictly implement them, so as to effectively prevent and control the potential safety hazards of the formwork support system.
With the development of the construction industry, the building decoration materials are changing with each passing day, and the building structure is becoming more and more complex. In this paper, a new concept is put forward, which is the professionalization of formwork support system builders, the self-renting and self-supplying mode of supporting system materials, and the budget of formwork support system combines the building area with the number and tonnage of members.

This paper discusses in detail the key points of "the importance of the positioning of the members in the formwork scheme" and "the influencing factors of the safety of the formwork support system". At the same time, it puts forward to eliminate or reduce the potential safety hazards of the formwork support system by strictly checking the construction process. In this paper, the description is simple and clear, and the point of view is pointed out, which can be used for reference and discussion by professional technicians in the field of construction, and also has certain promotion value.

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