

Performance-Based Design Method for Key Techniques in Construction Management of Buildings Translocation Project in China

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Abstract—Different from construction of new building, building relocation project utilizes many specific techniques in the phase of underpinning, separating, moving and arrival connecting, which, to a great extent, determine the cost, period and quality of construction management. Since every building shift project is unique and unrepeatable, a performance-based design method is proposed for planning the key techniques properly. In this method, the requirement of project and the characteristics of techniques are comprehensively considered first with the index of cost, time, influence to upper structure, controllability and scope, based on which the original plans are made. Then the feasibility analysis, utilizing the finite element model, is performed, which is based on the specific on-site performance of upper structure, together with the consideration of project requirements, to achieve the final optimized plan, which services for the completion of project management goal.

Index Terms—building translocation, construction objective, specific technique, performance-based design method

I. INTRODUCTION

Building monolithic moving was first practiced in China in the 1990s with a head frame in Xiao Hengshan [1]. Since then, this technology has witnessed a rapid development due to the remarkable advantages of short construction duration, low project cost, tiny influence on residents' life and work during construction, and environmental protection. Hundreds of existing buildings with different structure form dimension and in various environments have been successfully relocated in China, among which the maximum one is a fifteen-story frame-shear wall high building [2] in Laiwu, Shandong province.

During the moving construction, many specific techniques are applied ranging from underpinning methods in the preparation phase to the connecting methods after arriving to planned place, the design of which should consider the requirement of moving construction, the performance of upper structure and the condition of moving site comprehensively. However, since lacking of specific and systematic construction management theories and technique design standards [3], [4], the design and construction of building shift

engineering are usually guided and influenced by other similar engineering standards and practices. As a consequence, many uncertainties and unsuitable using of techniques appeared during the moving construction, which brought poor quality control problems like cracking, direction deviation, and even overturn of upper structure. These quality control problems result in not only the additional cost and extension of schedule, but also sometimes unrepaired damage or building collapse [5].

Therefore, this paper first analyzes the characteristics of the key techniques systematically including the aspect of construction management objective and the limitation in application. Then the performance-based design method for planning specific techniques properly is investigated, which combines the effect of project objective, the current condition of building and the feature of techniques simultaneously.

II. CONSTRUCTION MANAGEMENT OBJECTIVE

The construction management objective in building moving project encompasses the quality (service and safe performance) of building after construction and the total management goal to completing the project according to owner's satisfaction within the budget and in accordance with the specified schedule to meet the owner's defined purpose as well. It is heavily influenced by the subjective request from owner's expectations, as well as the objective request based on the financial resource, governmental standards, industry standards and regulations, which interacts and influences the overall outcome of the project [6].

The goal describes the cost, time and quality requirement of project, based on the combination of owner's expectations with the specific stipulations from related standards, rules and regulations, which is achieved through meetings and expert judgment [7]. Meetings are used to discuss and address the project request of moving construction, at which the attendees usually include the owners, consultants and project manager. After meeting, the expert judgment is often used to assess the resulted budget, schedule and quality request according to the performance of the existing building and the relevant standards, rules and regulations. A loop of meeting and expert judgment will be initiated if the assessment of the

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management request does not pass, which is illustrated in Fig. 1.

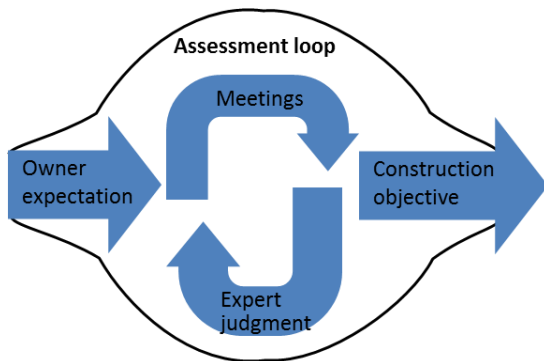


Figure 1. Assessment loop for getting management objective.

III. CHARACTERISTIC OF KEY TECHNIQUES

The specific processes in building relocation mainly include underpinning, separating, moving and arrival connecting of upper structure. There are several alternative technologies in each phase, which needed to be chosen properly for achieving the successful

construction of building shift engineering. Therefore, the features of commonly used techniques in these processes are comprehensively analyzed based on the factors from construction management objective and the limitation in techniques. These factors include the cost, time, and influence on upper structure, controllability and scope, which service for the performance-based design method. Among these indexes, the former three reflect the construction objective of cost, time and quality; the last two represent the application limit of techniques.

A. Underpinning Technique

Underpinning system is a kind of temporary supporting structure for superstructure during the moving construction, which should have enough strength, stiffness and the reliable connection, for it bears the load not only from superstructure directly, but from moving force, friction and other additional action. The most popular construction method for this supporting system is underpinning beam technology, including single-side beam mode and double-side beam mode [8]. Fig. 2 shows the schematic diagram of these two modes used in the underpinning structure of masonry wall.

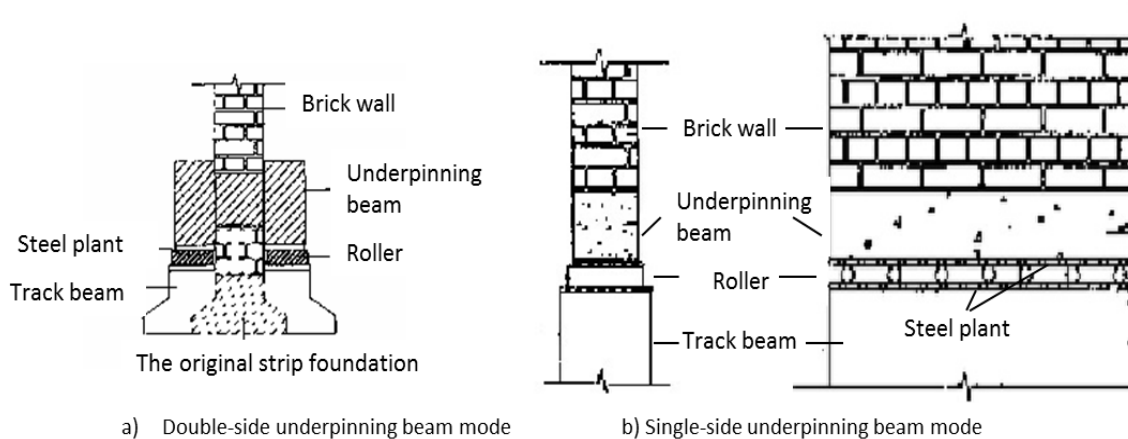


Figure 2. Schematic graph for underpinning system of masonry wall

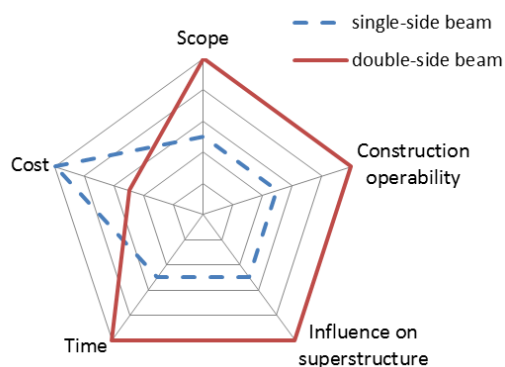


Figure 3. Character of single-side beam and double-side beam mode.

The radar graph in Fig. 3 illustrated the characters of these two methods, which shows that single-side beam method has a strong advantage in budget, while double-side beam method is shorter in schedule and less impact on upper structure.

B. Separating Technique

Separating operation is one of the most important phases during the construction of building translocation, since it is essential step to make the superstructure to be movable, meanwhile check the workability of underpinning system. The common technologies used to separate upper structure from foundation include manual cutting, semi-mechanical cutting and mechanical cutting [9].

In manual cutting method, all cutting off steps are finished by hand using hammer and chisel. In contrast, all separating operation in mechanical cutting process is finished by machine, including but not limited to diamond wheel machine, coring drilling machine and diamond wire saw cutting. While in semi-mechanical cutting method, some machines like pneumatic pick are used as assistant measures to manual cutting. The characters of these three methods are shown in Fig. 4, from which we can learn that manual and semi-

mechanical cutting method in China have a superiority on cost, but the defect with large effect on upper structure is also obvious. As to mechanical cutting, the situation is inverse. Considering that the buildings to be moved either have been used for many years or are as historical buildings, mechanical cutting method gains more and more preference in practicing.

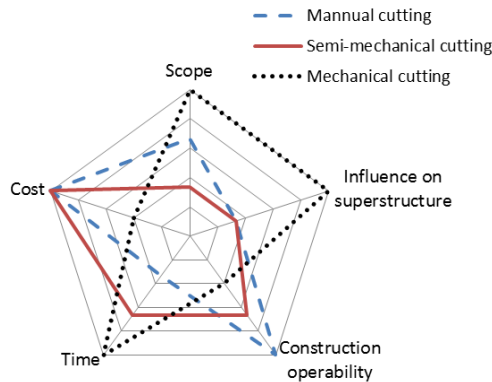


Figure 4. Performance of separating techniques.

C. Moving Technique

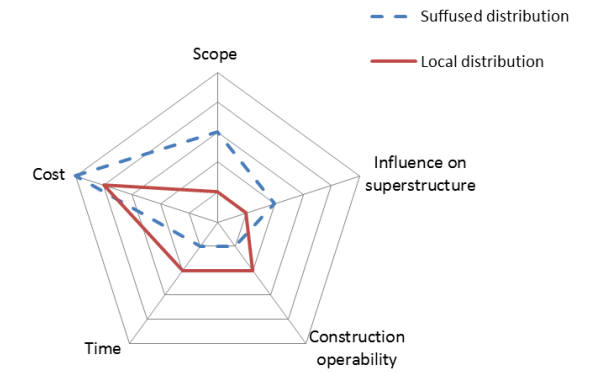
Shift mode combined with horizontal thrust applying mechanism regulates the moving process of upper structure: the super structure locates at the specific supports depended on the moving mode, after separated, and shifted to planned position by horizontal power through the chosen applying mechanism.

1) Shift mode

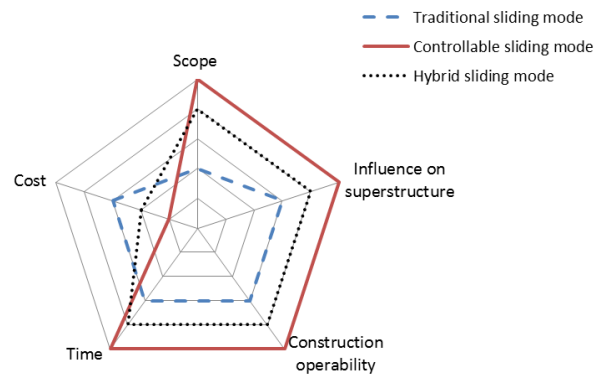
The most popular shift mode in China are rolling and sliding [9]. In rolling mode, the moving device is some kind of roller sitting between upper and lower track beam, by rolling of which the upper structure is relocated. The widely used types of roller include steel bar roller, seamless steel tube perfused with high-strength expansion concrete roller, seamless steel tube perfused with polymer roller and engineering plastics alloy roller. According to the placing way of roller, the rolling mode is divided into two classes, namely suffused distribution (the rollers are placed evenly under the whole underpinning system) and local distribution (the rollers are installed only under the corresponding position of support components).

As to sliding mode, the super structure relocated through the relative slip between the moving device and the lower track beam. According to the application of moving device, the slide mode could be classified into three categories: traditional type, hydraulic controllable type, and hybrid type. In traditional mode, steel block is used as slider to support the upper structure while sliding. Different from it, the hydraulic controllable type utilizes an internal force controllable jack as sliding bearing, which is computer-controlled and can effectively avoid the influence of orbital roughness and slider failure. In hybrid type, both steel block and controllable bearing are utilized as moving device.

Fig. 5 illustrates the character of them [10], from which, we can see that the rolling mode is cost-effective.



a) Feature of rolling shift mode



b) Feature of sliding shift mode

Figure 5. Characteristics of rolling and sliding shift mode.

Another type of shift mode is wheel plug-fuse type shift, which transfers buildings upon a special kind of flat-bed trailer. This shifting method is suitable for building relocation project with small load and long moving distance, which is widely applied in abroad [11]-[14]. In China, only few projects could satisfy the application condition of this method. For instance, an old villa had been moved 25 kilometers adopting this shift method by Shandong Architecture University in Jinan city [15].

2) Horizontal thrust applying mechanism

The frequently-used horizontal force applying mechanism contains incremental launching mode, mode and combination mode [16].

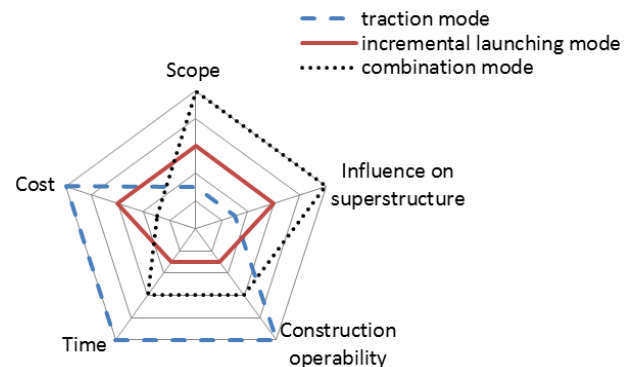


Figure 6. Performance of horizontal force applying methods.

Incremental launching method, using hydraulic jack or mechanical jack, applies force from the back of upper

structure to push it forward, different from which, the traction mode utilizes winch or jack to pull the superstructure forward from the front of it. Both of these mechanisms are applied in the combination mode to move the upper structure simultaneously. The comparison of these three modes is shown in Fig. 6, from which, we know that every method has its own priority.

D. Arrival Connection Technique

The connection method has a significant influence on the performance of upper structure in using period, which should satisfies both the safety requirement of related standards and the expectation of owners. The most common connection methods are secondary pouring connection and base isolated connection [17] in China. Secondary pouring method connects the upper structure with the new basement by pouring concrete after welding or overlapping the rebar between upper structure (the underpinning beam, column and shear wall) and the reserved rebar in basement, in which the enlargement measure in the connecting area is always applied to ensure the reliability of connection.

Base isolated connection method installs an isolation layer between upper structure and basement, which strengthens the seismic performance of upper structure to a large extent. The components used in isolation layer usually are laminated rubber bearing with passive dampers, sliding isolation bearing or rolling isolation bearing. The features of these two methods are shown in Fig. 7: direct connection have a priority of cost and construction operation, while isolated connection in other aspects.

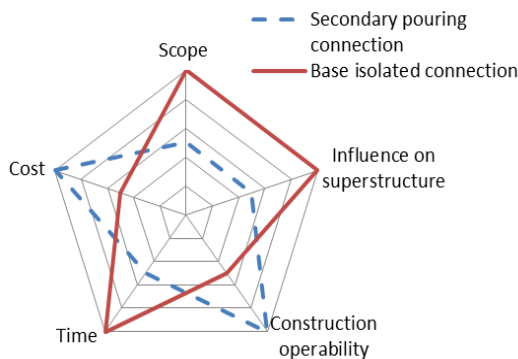


Figure 7. Comparison of secondary pouring connection and base isolated connection.

IV. PERFORMANCE-BASED DESIGN METHOD

Several Initial plans for techniques will be made after synthesizing the construction management objective with the characteristics of related techniques [18]. However, these plans could not guarantee the success of construction, since it does not take the performance of upper structure into consideration. Therefore, the performance-based design method is proposed to achieve the optimized techniques plan, in which the feasibility analysis of initial plans and the optimization are executed according to the project requirements and the current performance of building to be moved.

As it is illustrated in Fig. 8, in order to obtain the project oriented optimized plan for techniques, the construction management objective, the initial plans for techniques, as well as the detailed building and site information system should be completed first. This information system is established by gathering project related documents, on-site inspection of building and geological exploration, based on which, a finite element model of the upper building will be built to conduct the feasibility analysis of the initial technique plans. The feasibility analysis of techniques is one of the most significant processes of the performance-based design method, since it effectively combines the quality control requirements of project, the characteristics of related techniques with the current performance of building. To conduct feasibility analysis of initial plan, the finite element model of upper structure with the auxiliary components should be built first.

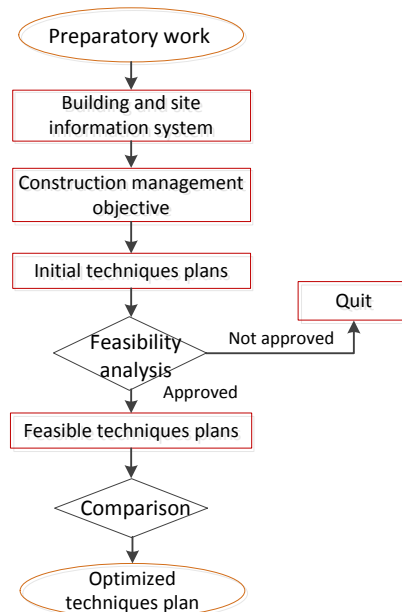


Figure 8. Process of performance-based design method for key techniques

Then the force and deformation condition of them will be analyzed by exerting the possible unfavorable actions during the application of related techniques respectively, based on which the feasibility of techniques will be identified, as well as the corresponding weak parts and its possible damage, which will identify the feasible plans which meet the expectation of owner and the performance control of upper structure during the translocation construction. Then the final optimized plan for techniques will be completed through the comparison between the budgets, schedule and quality related indexes in these feasible plans and the corresponding expectations from owners.

V. CONCLUSION

The construction of building translocation contains many specific phases including underpinning, separating, moving and arrival connecting, in which the utilization of

different techniques brings different quality results on upper structure. In order to achieve the optimized technique plan, the performance-based design method is proposed, which incorporates the construction management objective, the features of specific techniques and the performance of main structure comprehensively.

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more than 30 research papers since 1991 and been awarded by Chinese Local Government in six projects and one by State Government.

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