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APPLICATION OF MAST CLIMBING WORK PLATFORM(MCWP) IN FAÇADE RENOVATION OF HIGH-RISE BUILDINGS：A CASE STUDY

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ABSTRACT

This paper introduces a typical mast climbing work platform (MCWP) as a novel construction machinery designed for facade renovation in high-rise buildings. The application of the MCWP is illustrated through a real-world facade renovation project, which utilizes a combination of linear and L-shaped MCWPs. Additionally, this study establishes a finite element method (FEM) model of the linear and L-shaped MCWPs and presents the obtained results. The findings indicate that the serviceability of both linear and L-shaped MCWPs meets the required standards. Furthermore, compared to a suspended basket method based on time duration and cost, the MCWP approach for facade repair demonstrates significantly higher construction efficiency and cost reduction.

KEYWORDS

Facade Renovation, High-rise Building, Mast Climbing Work Platform, Construction Technology, Construction Machinery, Cost analysis

INTRODUCTION

Currently, urban renewal projects, which involve maintenance and repair of building facades, are rapidly gaining momentum across the world [1-7]. Traditional facade renovation methods primarily rely on scaffolding and suspended baskets. However, these approaches present higher safety risks, longer setup times, and lower construction efficiency, making them unable to fully cater to the ever-increasing demand for safer and more efficient practices [8]. In response to the limitations of traditional methods, mast climbing work platforms (MCWPs) have gained widespread adoption. An MCWP represents a novel category of construction machinery, powered by gears and racks. It features a highly reliable electrical and mechanical system, enabling it to securely elevate itself to the specific elevation of the building. Moreover, the platform where workers stand can be extended or retracted according to varying requirements. The entire structure can be easily assembled and disassembled, and the position of the platform can be effortlessly adjusted.

The process of façade renovation using MCWPs involves the following stages: construction design, installation, inspection, use, and dismantling. Among these stages, construction design is the most critical. When addressing buildings with numerous concave and convex corners during the construction design phase, a combination of linear and L-shaped MCWPs is recommended. Although numerous standards and publications offer guidelines for the safe use of MCWPs [9-14], they predominantly concentrate on linear-type MCWPs. For example, Wimer et al. [13] examined the effects of fall-arrest systems on MCWP stability; however, their findings are limited to single-column MCWPs and cannot be directly extrapolated to L-shaped twin-column MCWPs. Consequently, this restricts their widespread adoption in engineering practice. Nonetheless, considering that construction hoists and tower cranes are also attachment-type construction machinery, their stability analysis methods undoubtedly offer valuable insights for the research in this paper.

Numerical simulation has emerged as a widely adopted method to investigate the mechanical behavior of construction machinery [15-22]. For example, Zheng et al. [16] Calculated the stability of construction building hoist. Cheng et al. [18] assessed the safety and stability of tower cranes during operation. As building heights continue to rise, research on the anti-overturning capability of attachment-type machinery has become progressively more critical. In this context, the CFD (Computational Fluid Dynamics) method has been widely utilized to examine the anti-overturning capacity of attachment-type machinery, simulating the interplay between fluids and mechanical structures to offer more precise references for mechanical design and construction [20]. Simultaneously, with the advancement of test equipment, the incorporation of scaled model tests has also gained interest among scholars. For instance, Jiang et al. [21] demonstrated the stability variation patterns of tower cranes under incremental dynamic loads through a combination of numerical simulation and scaled model testing. Kenan et al. [22] similarly investigated the mechanical behavior of tower crane masts through scaled testing. In summary, the primary methods for investigating the stability of attachment-type machinery include numerical simulation, scaled model tests, and probability analysis based on data. Among these, numerical simulation is the most frequently employed method due to its efficiency and convenience. Nonetheless, scaled model tests entail higher experimental costs. In comparison to tower cranes and construction hoists, MCWPs are subjected to less complex external loads, which simplifies their stability research. Therefore, this article primarily utilizes numerical simulation to investigate the overall mechanical behavior of L-shaped MCWPs during the construction design stage.

After the dismantling step, in comparison to analogous repair methodologies (such as hanging basket and scaffolding), the cost-effectiveness of the MCWP approach remains to be substantiated. Nevertheless, given their efficiency and convenience, the potential applications of MCWPs in the repair sector merit further investigation and scholarly inquiry. As a result, this manuscript delineates the comprehensive process of employing linear and L-shaped MCWPs in a building renovation project, providing valuable insights and serving as a reference for analogous cases.

PROJECT OVERVIEW

Due to the deterioration and detachment of the external facades, two high-rise buildings in the 5th Shang Gang residential community necessitated renovation. These two buildings are located adjacent to Metro Lines 7 and 13 in Shanghai, China. As shear wall-frame structures, the structures boast a standard floor height of 2.8m, reaching an overall height of 43.2m. The renovation area extends over 100,385 m^2. The basic conditions of the buildings are also illustrated in Figure 1. These two buildings are nearly identical in design. As a result, the manager decided to employ a suspended basket method for one building and an MCWP method for the other. Although the MCWP method was introduced as a new technology to the company, the manager wanted to investigate whether its adoption improves efficiency and reduces cost.

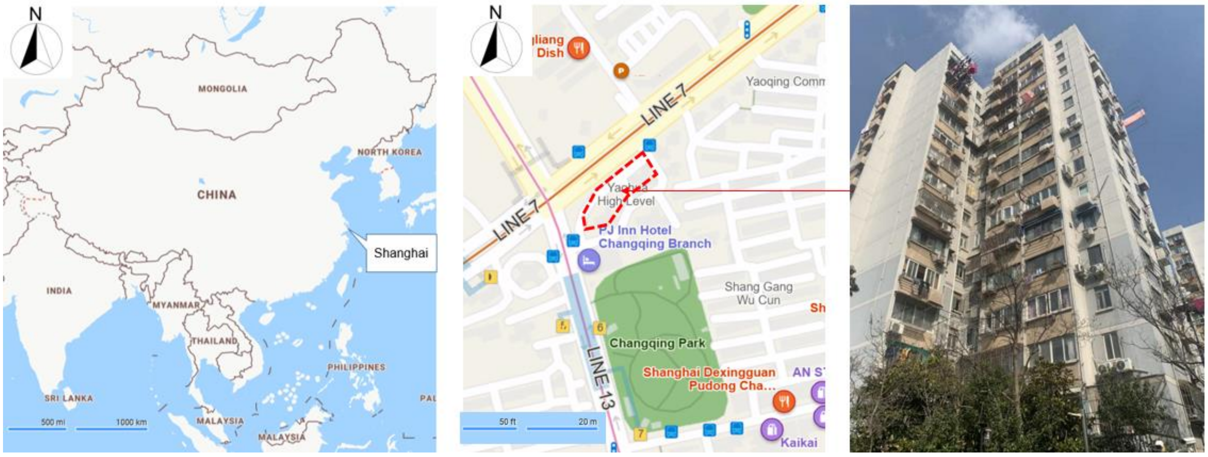
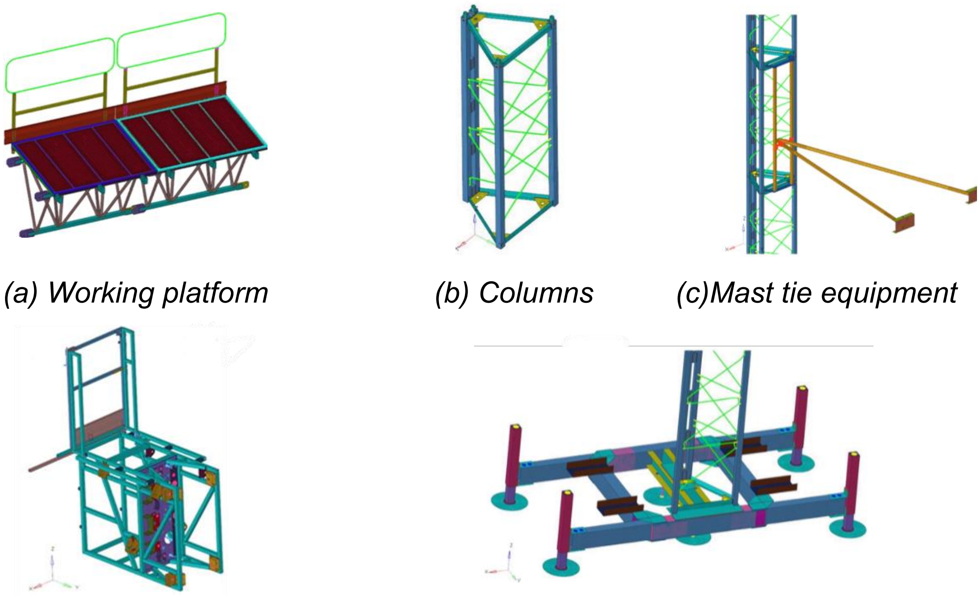


Fig. 1- Basic information about the building needed to be repaired

CONSTRUCTION PRINCIPLE

Components of the MCWP

The MCWP primarily comprises the following components: a base frame, columns, a working platform, a driving system, a control system, and mast tie equipment, as depicted in Figure 2. To avoid disrupting residents' communication, it's essential to predetermine the stacking location for these parts. Additionally, since the components need to be transported to the assigned site using a car crane, the load capacity of the outriggers must be considered. To alleviate stress concentration, wooden blocks should be placed beneath the outriggers. Prior to hoisting the components to the designated location, ensure that no one is in the vicinity of the car crane. Furthermore, it is crucial for the staff in charge to wear safety helmets throughout the entire operation to prevent potential safety incidents.



(a) Working platform *(b) Columns* *(c)Mast tie equipment*

(d) Controlling and driving system *(e) Base frame*

Fig. 2- Main Components of the MCWP

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Form of MCWP

MCWPs can be classified into two types based on the number of foundations: single-column and twin-column, as illustrated in Figure 3. The maximum span for single-column MCWPs is 9.8 meters, while for twin-column MCWPs, it is 27 meters. Additionally, the maximum span between adjacent columns in twin-column MCWPs is 18 meters. These specifications can be found in the specific regulations [23].

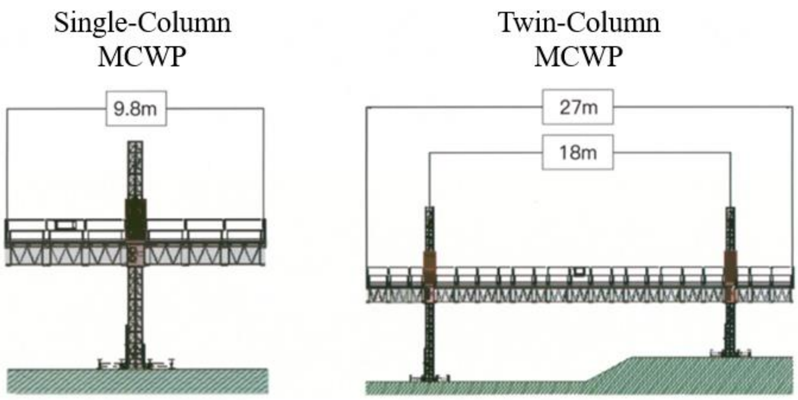

Fig. 3- Diagram of the single and twin-column WCWP

Twin-column MCWP can also be divided into linear, or L-shaped arrangements, as shown in Figure 4.

(a)Linear-type WCMP

(b) L-shaped WCMP

Fig. 4- Linear-type and L-type WCMP

Process principle for the MCWP

Firstly, assemble the base frame, control system mast, and working platform. Subsequently, as the platform rises, connect the MCWP to the wall using the mast tie. Next, activate the motor to supply power, which propels the platform to ascend to the designated floor. Once the platform comes to a halt, workers can commence renovation tasks for the primary structure.

OPERATION PROCESS FOR THE MCWP

Installation, Use, and Removal Process

As shown in Figure 5, the process of assembling and operating a WCWP undergoes several steps and should comply with certain standards [23]. The key points are listed below.

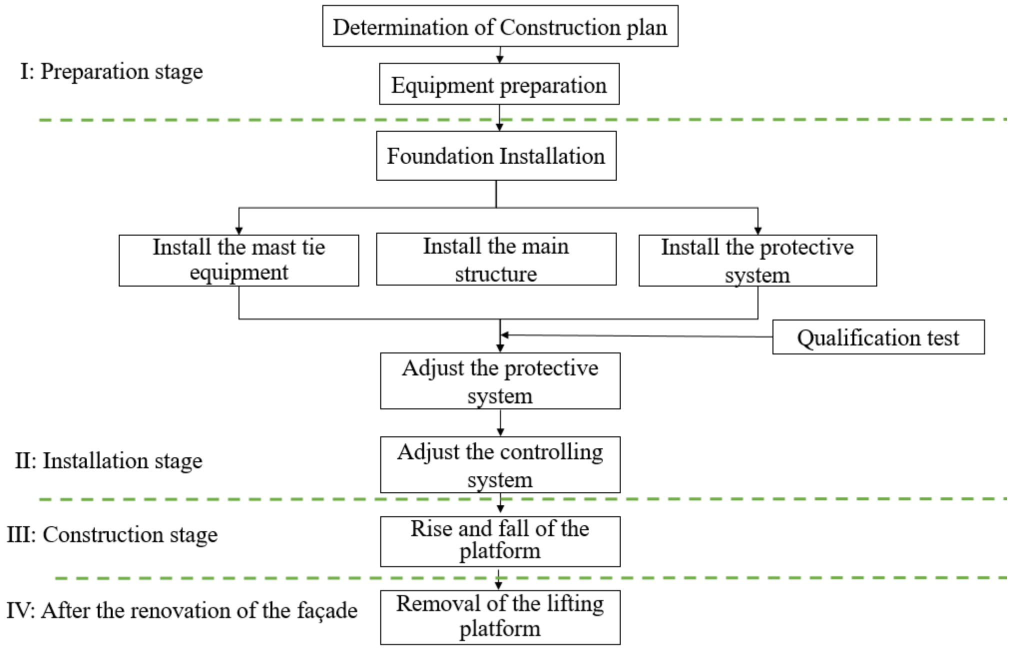

Fig. 5- Process flow

Determination of construction plan

It is crucial to develop a comprehensive plan for the renovation task. This plan can be broken down into three key steps. Initially, assess the surrounding environment, which involves identifying the optimal route for equipment transportation. Subsequently, investigate the building requiring repairs, paying particular attention to parameters such as the total height, floor heights, and the location of the building's girder beams, to determine the necessary height of the MCWP. Lastly, ensure that the MCWP layout can cover the entire perimeter of the building.

The total height of the MCWP is determined to be 43.8 meters, which matches the height of the building. The attached wall structure should be installed at the girder beam of each floor to ensure the stability of the MCWP during operation [23]. As depicted in Figure 6, due to the high-rise building's planar layout featuring numerous concave and convex corners, a combination of linear and L-shaped MCWPs should be employed in the arrangement.

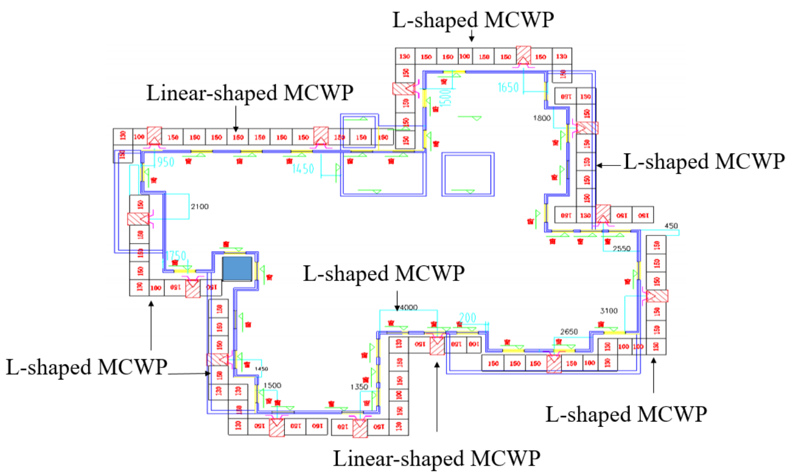

Fig. 6- Arrangement of the MCWP

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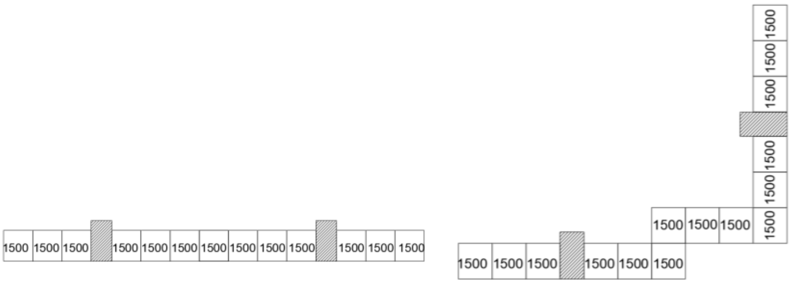
The spans for both the linear-shaped and L-shaped MCWPs are presented in Figure 7. However, these configurations have not undergone calculations, and the maximum deformations for these two types of MCWPs have not yet been determined. Consequently, it is essential to complete a structural analysis of the MCWP in advance.



(a) Linear-shaped (b) L-shaped

(mm)

Fig. 7- Schematic diagram of double-column MCWP

Initially, SolidWorks was utilized to create a 3D model of the MCWP's components. Following this, these models were imported into the meshing software Hypermesh for discretization. Lastly, the meshed model was transferred to the large-scale finite element software Ansys for analysis. The component is crafted from Q345 steel, possessing an elastic modulus of 210 GPa and a Poisson's ratio of 0.33. Its yield strength is 345 MPa, and the ultimate tensile strength reaches 512 MPa. The calculated load was determined according to the specifications outlined in the standard [23].

Figure 8 and Figure 9 presents finite element analysis results for linear and L-shaped MCWPs, offering a comprehensive understanding and evaluation of their mechanical properties under specified design loads. Furthermore, Figure 8 distinctly demonstrates the deformation distribution of the linear-type MCWP under the design load, with the maximum deformation occurring in the mid-span area of the platform, measuring 20.55 mm. This value is within the deformation limits established by pertinent standards, indicating that the linear MCWP possesses exceptional resistance to deformation and structural stability under these loading conditions.

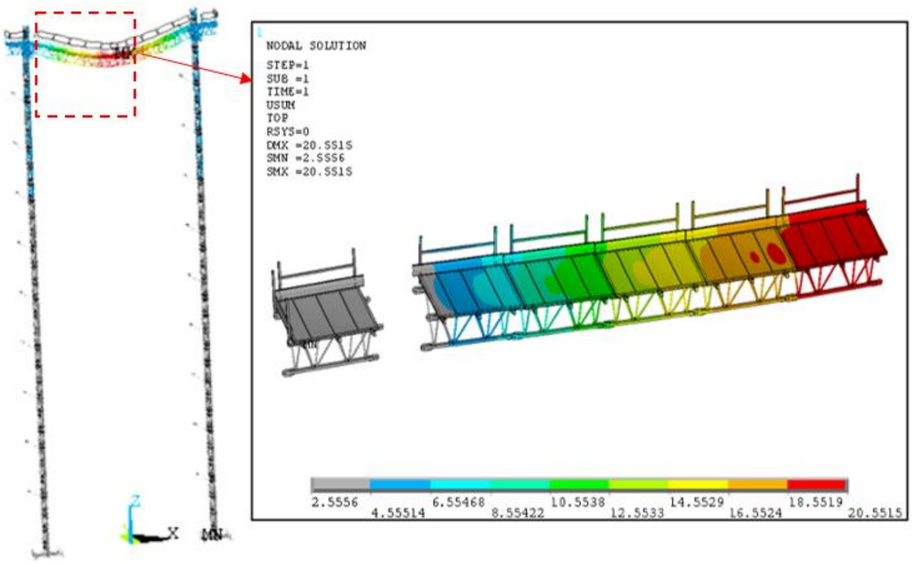


Fig. 8- Deformation cloud of Linear-MCWP

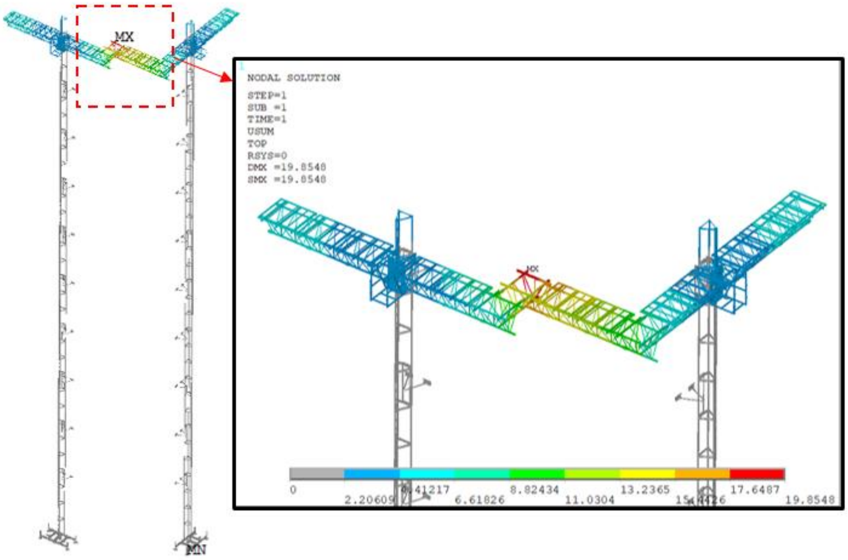


Fig. 9- Deformation cloud of L-shaped MCWP

At the same time, as a non-standard structure comprising two single-column MCWPs, the deformation characteristics of the L-shaped MCWP are not explicitly outlined in the current specifications. It is particularly crucial to precisely calculate and analyze the deformation of the L-shaped platform to ensure its safety and reliability in engineering practice. Moreover, Figure 9 indicates that the maximum deforma*tion of the L-shaped MCWP was* 19.85 mm, which also complies with the general specification requirements.

In summary, analyzing the deformation of these two types of platforms not only verifies their structural safety under design loads but also highlights the significance of deformation values as essential indicators for assessing the serviceability of MCWP. Specifically, steel structures inevitably experience deformation when subjected to loads, and the magnitude of this deformation directly impacts the safety and stability of the structure. When the deformation exceeds acceptable limits, it can lead to structural failure or safety incidents. Hence, precise calculation and control of deformation through finite element analysis are essential prerequisites for ensuring the safe operation of MCWP.

Installation of foundation

The determination and installation process for the foundation is illustrated in Figure 10, which encompasses four scenarios:

1. When the foundation must be installed in a courtyard, negotiation with the homeowner is necessary. If negotiations are unsuccessful, adjustments to the construction plan and adoption of a suspended basket method become necessary.
2. When the foundation must be positioned on a flower bed or greenery with poor soil mechanical properties, the soil can be excavated and removed. If the soil exhibits good engineering properties, a dynamic compactor can be employed to ensure that the foundation's bearing capacity is not less than 60 kPa, by the standard [24].
3. When the foundation must be constructed on an asphalt road, merely adjusting the pedestal to the same level is required.
4. When encountering steps, the flatness of the MCWP can be aligned to the same height using a steel cushion.

The concrete slab in use measures 3 meters in length, 3 meters in width, and 0.2 meters in thickness. It incorporates a reinforced grillage, with a spacing of 20 millimeters between the horizontal and vertical steel bars and a spacing of 0.1 meters between the upper and lower grillages. Upon completion of the installation, a fence should be erected within 1 meter of the foundation perimeter to deter people from approaching.

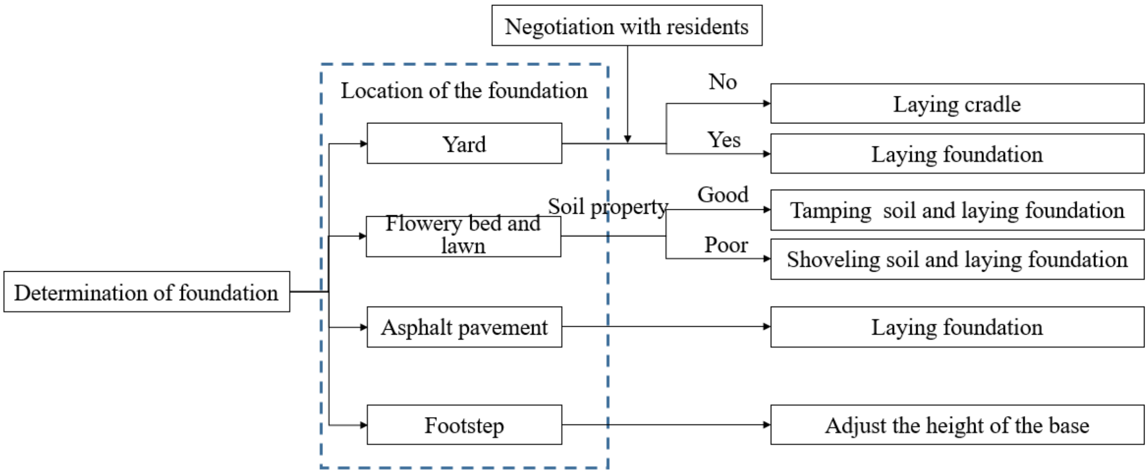
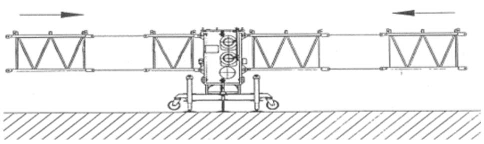
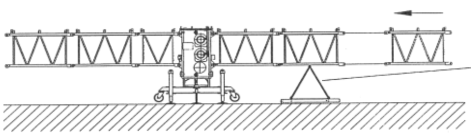
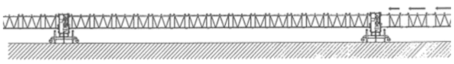
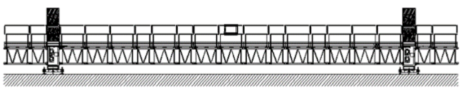


Fig. 10- Process flow for handling the foundation

Installation of the main structure

The installation process for the primary components of a twin-column MCWP is detailed in Table 1. Despite the existence of various arrangements, the twin-column linear type remains the most prevalent and is extensively utilized in construction sites.

Tab. 1 - Process for installing a twin-column MCWP

Step	Diagram	Content
1		Install the base frame and driving system on the left side; Adjust the base's level and verticality and test it with a leveling device. After installing the bottom parts, install the first cantilever platform beam on both sides and fix them with several pins to the driving system.
2		Install the other base frame.
3		Install the driving system and the right-side overhanging platform using three pins.
4		Then install guardrails and safety gates. The mast tie is installed to the wall with the elevation of the platform.

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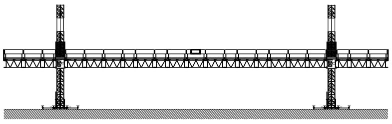
5		Install the ladder and bolt it tightly to the base.

Installation of the mast tie

When employing the MCWP method for high-rise buildings, wind load must be taken into consideration. To counteract lateral loads and provide stability to the structure under repair, a mast tie equipment is utilized. As depicted in Figure 11, the mast tie equipment comprises the following components: chemical bolts, high-strength bolts, anti-slip fasteners, oblique rods, mast tie rods, mast tie frames, and connecting bases. An oblique rod is added to the upper portion of the mast tie equipment, and the chemical bolt type is M16×180 mm, with a required bolt torque of 75 N·m. The angle of the steel tube should be kept within the range of 30-55°. On-site pull-out tests are performed for the chemical bolts, ensuring that the drawing force exceeds the value specified by the standard.

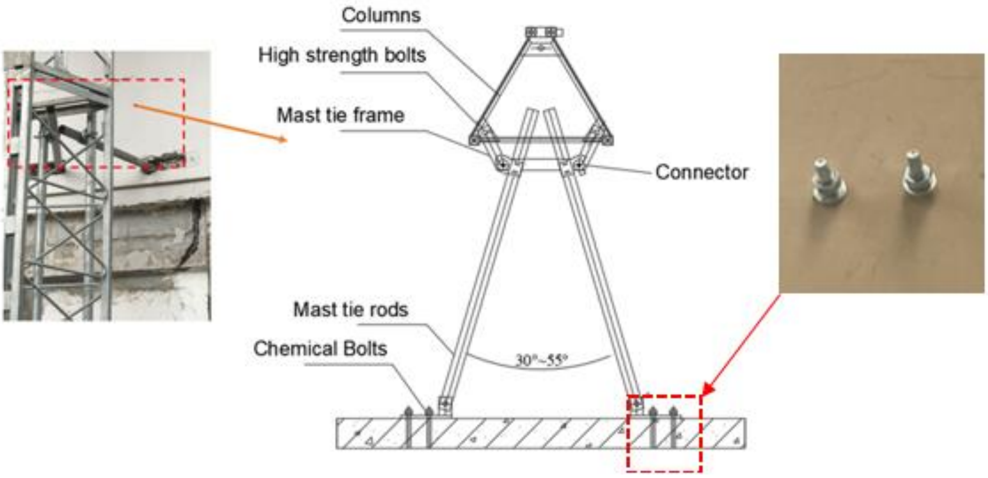


Fig. 11- Mast tie

Installation of the other equipment

Other protective equipment is shown is Figure 12. The platform guardrail plays a crucial role in ensuring that neither materials nor individuals fall to the ground (Figure 12(a)). Additionally, safety ropes are tied to the platform to avert failures of the safety device (Figure 12(b)). To protect against high-altitude falling objects during the repair process, a protective shed is installed above the pedestrian walkway (Figure 12(c)).

(a) Guardrail *(b) Safety rope* *(c) Protective shed*

Fig. 12- Protective Equipment

Beyond these protective measures, special attention must be paid to the setup of the electrical system. The electric control box should be installed in the center of the platform and secured with bolts. After securing the power cable, workers should verify the input voltage and insert the cable of the driven motor into the electrical control box. The cable should be fastened to the platform beam, insulated, and securely tied. The power supply specification for the motor is a three-phase five-wire system, incorporating both grounding and zero connections. Each motor has a rated current of 3A and a starting current of 40A. It is imperative to confirm that grounding and zero connections are effectively established to prevent electric leakage. The installation of the electric control box and cables should be carried out by qualified electricians.

COST ANALYSIS AND COMPARISON

The procedures for renovating walls typically involve waterproofing, primer painting, sanding, and coating. For one building in the same residential area, the general contractor utilized an MCWP, while for the other building, a hanging basket was employed. The construction cost comprises labour, machinery, and material expenses. In this case, machinery and material costs have been converted into labour costs. A comparison of the actual cost and duration between utilizing an MCWP and a suspended basket is presented in Table 2. The facade repair area is 5,000 square meters. The MCWP method took 104 days, whereas the suspended basket method required 196 days. Assuming a labour cost of 400 yuan per day for the MCWP method and 300 yuan per day for the suspended basket method, the total cost amounts to 41,600 yuan for the MCWP method and 58,800 yuan for the suspended basket method, respectively. As evidenced by the table, employing an MCWP method is more efficient and cost-effective compared to using a suspended basket.

Tab. 2 - Renovation cost for using the MCWP and suspended basket

	Procedure	Using an MCWP			Using a suspended basket		
		Number of workers (per person)	Time (per day)	Duration for each step	Number of workers (per person)	Time (per day)	Duration for each step
1	Whitewash	2	4	8	2	5	10
2	Exterior wall polishing	6	3	18	6	8	48
3	First-time whitewashing	6	3	18	6	8	48
4	Levering with plaster	6	2	12	6	6	36
5	Second-time whitewashing	6	3	18	6	10	60
6	Coating of the wall	6	5	30	6	11	66
	Total(days)	104			196		

DISCUSSION

Based on the on-site practical application of the MCWP method, our findings indicate that it possesses notable advantages in terms of safety performance and construction efficiency.

Firstly, the utilization of MCWP has significantly enhanced construction safety. Its integrated protective, electrical, and mechanical systems ensure safety and reliability throughout each phase of the construction process. This comprehensive approach to safety minimizes risks. Secondly, economic data from a comparable high-rise building in the same community, which was repaired using traditional basket methods, highlights that MCWP outperforms in terms of construction efficiency and cost reduction. This is primarily attributed to its innovative lifting mechanism and flexible platform design, enabling construction personnel to complete tasks more expeditiously and effectively.

The contribution of this paper lies in the refinement of construction design steps. Specifically, the platform selection process incorporates a blend of linear and non-standard platforms. To validate the structural stability and reliability of these platforms, finite element method (FEM) simulations were conducted. This flexible arrangement of platform types is made possible through a thorough understanding and meticulous consideration of the specific conditions at the construction site.

Nevertheless, this study acknowledges certain limitations and areas for improvement. For example, the sample size is confined to a single urban renewal project, which may not fully encapsulate the diverse performance capabilities of MCWP across varying environments. Future research should endeavour to expand the sample scope to more comprehensively assess the adaptability of MCWP. Furthermore, there is potential for incorporating cutting-edge technologies, such as the Internet of Things (IoT) and big data analytics, to achieve intelligent control and optimized management of the platform.

CONCLUSION

This paper provides a detailed account of the application of MCWPs in urban renewal projects, with particular focus on the construction techniques used for the facade repair of high-rise buildings. By comparing the facade repair methods that utilize hanging baskets, this paper highlights the advantages of MCWP in terms of safety, efficiency, and cost. And the following key conclusions can be drawn:

1) A combination of linear and L-shaped MCWPs is suitable for buildings with concave and convex corners.
2) In comparison to traditional facade renovation methods, the MCWP approach offers improved safety, reliability, and performance.
3) The overall MCWP structure is simple to install and features a higher turnover rate.
4) Employing the MCWP method for high-rise buildings abbreviates the overall construction period and reduces total costs.

In summary, the MCWP is poised to assume a pivotal role in the future of urban construction. Currently, several forward-thinking companies are actively incorporating MCWP into their research and development initiatives, particularly in the realm of exterior wall plastering robots. These efforts are directed towards realizing the vision of unmanned facade repair construction, thereby addressing the challenges associated with traditional manual methods and fostering a new era of smart construction practices.

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