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Study on the Green Construction Technology Model of Aluminum Alloy Formwork based on Multi Factor Coupling

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In order to improve the quality and performance of the green construction technology model of aluminum alloy formwork, the multi factor coupling method is proposed in this paper. The aluminum alloy system formwork encourages quality control from an early stage, i. e from the planning and design stages, through the manufacturing process, packing, delivery to site, erecting on site, dismantling and repeated assembly and removal process. In turn this facilitates good quality of concrete. The experiment result shows the system has been proved to be successful in many countries and cities. As the applicator of the aluminum alloy system formwork, it is proved to say that further invention of semi-labour system by the use of construction R&D might resolve the intensive labour problem. It will take time to improve the design and erection in a more scientific and mechanical way in order to achieve an objective of using less labour

1. Introduction

Nowadays, diversification, standardization and commercialization of formwork technology have become a growing trend in China. Aluminum alloy formwork technology, as a new technology, has been successfully applied in housing construction projects. However, its further wide use should be supported with corresponding quality standards. Otherwise, it will be subjected to affect by inferior products. To promote the formation of aluminum alloy formwork's quality systems and the application of new materials and new technology, and to achieve green construction, a systematic study on aluminum alloy formwork technology has been done in this paper (Zhu et al., 2014). Support systems of aluminum alloy formwork that is an early split system, has been theoretically researched. Based on the calculation models established by ADINA, one of the most famous finite element software, force status of aluminum alloy formworks and stress distribution of concrete structures after removing formworks are analysed (Rath et al., 2014). It is shown that the position of the maximum stress in concrete structures is at sideline of the strut by the side of the beam, the same at the lower of the beam connected to the plate. Thus, struts should be enhanced at both sides in order to ensure construction safety when conducting the construction of big beams. In addition, moment of inertia of struts needs to be increased with the number of layers (Lin et al., 2008).

Construction processes of aluminum alloy formwork have been systematically researched, including application range, manufacturing and assembling formworks, detailed working practice, and assurance measures of safety and quality. The main conclusions are as follows: First, aluminum formwork is suitable for the construction of ultra-high-rise structures which has more standard layers, as well as simple shape structures and limited construction time. Secondly, the quality of raw materials is very important. Thus, it should be better those technical personnel from project department assists to instruct machining formworks. Thirdly, formworks should be continued to optimize in the construction process. Finally, formworks should be timely corrected and maintenance after working.

The PDCA quality-control method has been used to analysis the main factors that affect the quality of concrete structures forming by aluminum alloy formwork. Corresponding solutions have been proposed to check the effect of implementation. The results show that the slump and the vibration method and formworks maintenance are the main factors causing the surface pock or bubbles. It will be better to improve the quality of concrete structures by controlling the size deviation and making the formwork pre-oxidation and controlling the slump about 160mm.All in all, Aluminum alloy formwork technology has been researched in this thesis

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from both theory and application. The technology of removal lever of aluminum formwork, which has applied for Chinese utility-model patents successfully, was independently developed during the experimental process. Figure 1 shows the aluminum alloy formwork.

2. Overview

Aluminum alloy formwork has been extensively used in construction. For its use, many difficulties and some questions have been brought forward. Because its integrity and accuracy, the use of aluminum alloy formwork improves the quality and the efficiency of the building.

Aluminum formwork system is a new kind of construction formwork system, which has been put into use for many years around the world, but it is still in the early stages of exploration and research in China. So it is of great importance to research on aluminum formwork system. Rath's paper investigates the mechanical properties of the Aluminum Formwork, Aluminum Alloy Frame Structure and Zhuhai City Garden Template Structure. Mechanical properties analysis and wind-induced vibration response of the structure is checked by the computer simulation (Marsh et al., 1975). First, a finite element static analysis was carried out on the standard aluminum alloy template and slab template; And then compare it to experimental results and conclusions using the theory of basic structural mechanics principle to analysis the aluminum alloy template. Calculation results show that the bearing capacity and deformation capacity of the aluminum alloy template meet the relevant norms and verify the stability of finite element analysis. Using the finite element to analysis Template for aluminum alloy frame structure, and calculate the load displacement curve of the aluminum alloy template structure, nonlinear characteristics, mechanical properties such as structural stability, and the results of analysis is consistent with experimental results.

Based on this, a finite element model of template structure was established and the static wind response of the template system and wind-induced vibration response is respectively studied in Lin's paper [3]. First of all, analyze the static response of the structure. Then, the association of wind speed time series of the nodes are considered, Auto-Regressive (AR) model is employed to simulate node randomly fluctuating wind speed time series. By using programs written by simulate wind speed time series, and analysis wind- included vibration response of the template structure. The calculation results shows: the deformation occurred on the template for the most part due to wind load and the resistance to overturning and sliding of the structure resistance can be guaranteed by self- weight of template and relevant components (Xie et al., 2011).

1) The aluminum alloy system formwork consists of over 200 items, including standard panel and accessories with fine tolerances. The corner sections are designed for angle fixing and are easy to remove after casting of concrete. A special feature of the design is that it provides for removal of slab panels without disturbing the supporting props. A set of system formwork consists of a mound for the monolithic pouring of concrete walls, columns, beams, slab, staircase, and bay windows, etc.

2) The aluminum alloy sections are extruded or manufactured to an effective width and height that can be easily handled by a single worker (Soetens et al., 2010).

Consequently, the aluminum alloy formwork does not rely on heavy cranes or other heavy construction plant and equipment. However, the individual panels can be assembled together to form larger panels to minimize repeated dismantling and assembly, there- by saving cost, especially in the case of typical floors. All individual components of the system form- work can be connected by simple pins and wedges. The wall forms arc removed 12 hours after pouring and for slab forms;the period is 36 hours after concreting. By means of the aluminum alloy formwork, one set of system formwork can be repeatedly used over 200 times for a 5 days cycle construction. Figure 2 shows the aluminum alloy formwork in supporting structure (Miller et al., 2006).

Figure 1: The aluminum alloy formwork

Figure 2: The aluminum alloy formwork in supporting structure

3. Advantages

The aluminum alloy system formwork allows 100% of the building i.e. all internal walls, all external walls stairs, lift shafts, balconies, and sun hoods, etc.) (Tam et al., 2006) To be constructed at a rate of 4 days per floor.

This compares favorably with the traditional approach which will take at least 12 days a floor (for columns, beams and slabs only-then the infill walls have to be built and plastered). As a result, the total structure is completed in a third to a quarter of the time required to build conventionally. Thus developers can make a reduction on project financing costs, and site overheads can also be significantly reduced (Cheng et al., 2006).
The flat, off-form finish produced by the aluminum alloy system formwork simply requires a 2 -3 mm skim coat before decoration, thus eliminating the need for plastering (Often, clean plastering sand is scarce, and if poor sand is used, this leads to unraveling of plastered surfaces in a short period of time). In addition, all the elements of the building arc accurately dimensioned, and arc vertical, horizontal, and square in plan and section as intended, so that remedial works to correct inaccuracies can be eliminated (Jolicoeur et al., 2015).
As service collars can be accurately located and cast in as the slab concrete is being poured, leaks arc eliminated. This is a major hidden saving as builders arc very reluctant to admit (even to them- selves) the true costs of locating and remedying leaks, often these tend to be covered by the contingency figure.
The props of the aluminum alloy system formwork arc modified to form an integral part of the formwork system so that they do not needed to be moved to release the slab forms-and therefore the riprapping of the slab is not necessary. The elimination of riprapping means the aluminum alloy system formwork is inherently safer to use on site than traditional formwork comprising timber and plywood, and any other systems that require re-propping after the removal of forms. In the event that 4 days per floor is expected, 4 to 5 sets of props arc required.
The aluminum alloy system formwork eliminates the need for skilled plasterers as noted above, and it also eliminates the need for skilled carpenters and block layers. Projects have often been seriously delayed because of the unavailability of these skilled trades.
Normally tower cranes arc extremely busy especially when used for the vertical transportation of materials. It is a merit if crane is not required so often for the movement of the forms as the construction proceeds. Thus by using aluminum formwork, the crane is more available for concrete and steel placing and for lifting and transporting other materials. The crane is only required for moving the forms down from the top of the completed building.
The aluminum alloy system formwork allows consideration of a `load bearing walls' structural design approach. A LBW design will always be more structurally efficient than a traditional reinforced concrete frame approach, and will give a very much stronger building. It will therefore be less expensive to construct as well as less expensive for the provision of the foundation. Because the system Formwork is modular and flexible, it can be applied to any architectural or structural layout. Thus, the designers can be as creative as they like, and to be confident that advantage can be taken of the system approach for construction.
The aluminum alloy system formwork is extremely adaptable and flexible. It is rarely necessary to amend building design to accommodate the system. Based on the architectural and structural drawings of a proposed building, a process of computer modulation is carried out. This process requires that iteration and optimization techniques arc utilized to select the most economical and practical fitting of the individual components that comprise the system formwork. A large database containing all Stan lord pieces of equipment is used in order to produce the shell drawing in a short period of time.
For the multi factor coupling method, the basic algorithm is shown in the following equations [9-10]:

$$\varphi_{ji}(\mu_j) = \exp\left(\frac{-(\mu_j - C_{ji})^2}{{b_{ji}}^2}\right), \text{for } i = 1, 2, \ldots, H \tag{1}$$

In this space, the mth multidimensional receptive-field function is defined as

$$\Phi_m(\mu) = \prod_{j=1}^{L} \varphi_{ji}(\mu_j), \text{for } m = 1, 2, \ldots, N \tag{2}$$

The function can be written in a vector notation as

$$\Phi(\mu, C, b) = [\Phi_1, \Phi_m \ldots, \Phi_N]^T \tag{3}$$

where $C = [C_{11}, \ldots, C_{L1}, C_{12}, \ldots, C_{L2}, \ldots, C_{1H}, \ldots C_{LH}]^T$, and $b = [b_{11}, \ldots, b_{L1}, b_{12}, \ldots, b_{L2}, \ldots, b_{1H}, \ldots b_{LH}]^T$.
The weight memory space with N components can be expressed in a vector as

$$W = [W_1, W_m, \ldots, W_N]^T \tag{4}$$

The activated weights in weight memory space, which can be written in a vector form as

$$y = W^T \Phi(\mu) \tag{5}$$

The state variables and the desired values can be defined as follows:

$$z_1 = x_1 - y_d \tag{6}$$

and

$$z_2 = x_2 - \alpha_1 \tag{7}$$

The following tracking error dynamics is shown as:

$$\dot{z}_1 = \dot{x}_1 - \dot{y}_d = x_2 - \dot{y}_d = z_2 + \alpha_1 - \dot{y}_d \tag{8}$$

The first derivative of the Lyapunov function can be written as

$$\begin{aligned}\dot{V}_1 &= z_1^T \dot{z}_1 = z_1^T(\dot{x}_1 - \dot{y}_d) = z_1^T(\dot{x}_1 - \dot{y}_d) = z_1^T(x_2 - \dot{y}_d) \\ &= z_1^T(z_2 + \alpha_1 - \dot{y}_d) = -\lambda_1 z_1^T z_1 + z_1^T z_2\end{aligned} \tag{9}$$

From (2) and (6), it can be obtained:

$$\dot{z}_2 = \dot{x}_2 - \dot{\alpha}_1 = -M^{-1}Cx_2 - M^{-1}(G_g + d) + M^{-1}\tau - \dot{\alpha}_1 \tag{10}$$

τ is selected as

$$\tau = -\lambda_2 z_2 - z_1 - F \tag{11}$$

Then we can get:

$$V_2 = V_1 + \frac{1}{2} z_2^T M z_2 \tag{12}$$

$$\begin{aligned}\dot{V}_2 &= \dot{V}_1 + \frac{1}{2} z_2^T M \dot{z}_2 + \frac{1}{2} \dot{z}_2^T M z_2 + \frac{1}{2} z_2^T \dot{M} z_2 \\ &= -\lambda_1 z_1^T z_1 + z_1^T z_2 + z_2^T M(\dot{x}_2 - \dot{\alpha}_1) + z_2^T C z_2 \\ &= -\lambda_1 z_1^T z_1 + z_1^T z_2 + z_2^T(-Cx_2 + Cz_2 + \tau \\ &\quad - M\dot{\alpha}_1 - (G_g + d)) \\ &= -\lambda_1 z_1^T z_1 + z_1^T z_2 + z_2^T(f + \tau) - z_2^T(G_g + d)\end{aligned} \tag{13}$$

$$\dot{V}_2 = -\lambda_1 z_1^T z_1 - \lambda_2 z_2^T z_2 + z_2^T(f - F) - z_2^T(G_g + d) \tag{14}$$

The ideal weight W from (10) and expressed as

$$F = W^T \Phi(\mu) \tag{15}$$

Define the estimate of the value of (11) as

$$\hat{F} = \hat{W}^T \Phi(\mu) \tag{16}$$

It's provided by the adaptive weight law. So estimation error of the weight is

$$\tilde{W} = W - \hat{W} \tag{17}$$

The positive values Wmax as follows:

$$\|W\|_F \le W_{\max} \tag{18}$$

The adaptive weights law is defined as

$$\dot{\hat{W}} = -kG\|z_2\|\hat{W} - z_2^T G\Phi(\mu) \tag{19}$$

By differentiating the yields of V, we obtain

$$\begin{aligned}\dot{V} &= \dot{V}_2 + tr\left\{\tilde{W}^T G^{-1}\dot{\tilde{W}}\right\} \\ &= -\lambda_1 z_1^T z_1 - \lambda_2 z_2^T z_2 + z_2^T(f - F) \\ &\quad - z_2^T(G_g + d) + tr\left\{\tilde{W}^T G^{-1}\dot{\tilde{W}}\right\} \\ &= -\lambda_1 z_1^T z_1 - \lambda_2 z_2^T z_2 + z_2^T(f - \hat{F} + \hat{F} - F) \\ &\quad - z_2^T(G_g + d) + tr\left\{\tilde{W}^T G^{-1}\dot{\tilde{W}}\right\}\end{aligned} \tag{20}$$

The unknown function f is such that

$$\left\|f - \hat{F}\right\| \le \varepsilon_0 \tag{21}$$

4. The experiment result and data analysis

1) Once it has been decided to use the System Formwork for a particular project, the production of a Shop Drawing, based on the Architectural drawings with cross reference to the Structural Engineering drawings will be finished within 14 days and ready for submission. In cases where some dimensional discrepancies occur between two supplied sets of drawings in the course of preparing the Shop Drawing, the designers will attempt to resolve these discrepancies with the agreement of both the Architect and Structural Engineer. This must be done prior to submitting the Shop Drawing to the Client for confirmation [11-12].

2)The Shop Drawing is the final dimensioned layout from which the design for the set of The System Formwork is produced. The design of a set of formwork is an extremely intricate process, where separate consideration must be given to each and every detail required to create the building shape. Further, the shape and size of each piece of formwork relates to the shape and size of every other adjacent and opposite (in the case of vertical formwork) component. The levels of design complexity can be fully appreciated when it is comprehended that the holding pattern must be designed with assembly in mind this occurs in the same plane, at right angles and at other angles. Hence, it is necessary for at least two holes on each edge to match with the other adjacent panels, for the purpose of the fixing.

3) Because an apparently small change in the layout will have dramatic `knock-on' effect on the whole formwork design, it is better not to proceed with the manufacture process until the Shop Drawing is confirmed by the Client as approved for construction. Confirmation of the Shop Drawing must be regarded by all parties involved as the end of the building design process.

4) If changes arc insisted upon by the Client after confirmation of the Shop Drawing, there will be serious and unavoidable consequences: additional costs will be incurred and time will be lost against the program. Furthermore, changes insisted upon after construction has commenced and has the potential to cause a greater degree of, and can be very expensive. Figure 3 shows the comparison curve in the proposed method.

(1) Material Package and Delivery. This is one of the important steps required to save labour in the erection. After manufacture, materials arc packed on pallets in accordance with the numbering system assigned to facilitate easy lo- canon of panels so that they can be erected in the correct sequence. When the pallets arc delivered to the specified location, the wall panels' arc erected according to the marking number as shown on the shop drawing. Different colored lettering identifies direction and location. Workers arc normally instructed not to use differently marked panels even though they look similar; this will ensure fixing accuracy.

(2)Storage on Site If the working level is not ready for erection; the pallet materials must be stored systematically with clear identity such that the required panel can easily be located and picked up for erection. Pre-planning of storage on site results is in a good logistic support in the erection.

(3) Erection Apart from the manufacturing process, the erection of the aluminum alloy formwork on site is an important step to put the planning into reality. It is vital to establish the daily construction cycle of work and then to co-ordinate and manage the other trades such as the fixing of steel reinforcement, followed by ducting works for electrical and mechanical installations and the placing of concrete. The formwork system requires a disciplined and highly efficient working schedule that ensures other related trades will follow in a timely manner. This coordination of trades and the cycling of equipment at optimum speed results in buildings being constructed at rates of 4 to 5 days per stores as compared to traditionally expected rates of 10 to 14 days per stores without the removal of props as specified in the specification. Figure 4 shows the experiment result.

Due to the fine tolerances achieved in the machined metal components, accurate concrete forms and shapes can be obtained repeatedly; hence exacting standards can be achieved, thereby achieving quality and accuracy. This enables plumbing and electrical fittings to be prefabricated with certainty. The construction accuracy of the concreted works-with the barest of surface imperfections or blemishes, will also benefit other finishing trades such as tiling and the fitting of doors and windows.

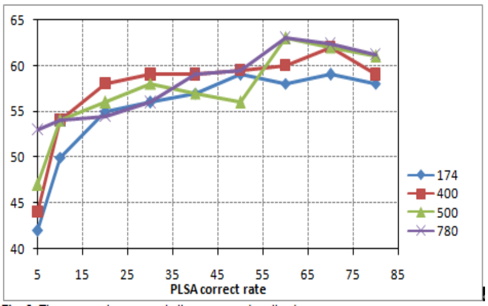

Figure 3: The comparison curve in the proposed method

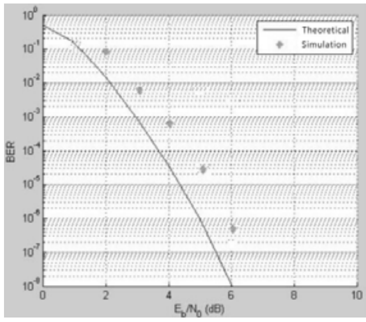

Figure 4: The experiment result

5. Conclusion

The purpose of this paper is to research on the green construction technology model of aluminum alloy formwork based on multi factor coupling method. The aluminum alloy system formwork allows consideration of a load bearing walls' structural design approach. The aluminum alloy system formwork encourages quality control from an early stage, i. e from the planning and design stages, through the manufacturing process, packing, delivery to site, erecting on site, dismantling and repeated assembly and removal process. A LBW design will always be more structurally efficient than a traditional reinforced concrete frame approach, and will give a very much stronger building. It will therefore be less expensive to construct as well as less expensive for the provision of the foundation. In turn this facilitates good quality of concrete. The experiment result shows the system has been proved to be successful in many countries and cities. In cases where some dimensional discrepancies occur between two supplied sets of drawings in the course of preparing the Shop Drawing, the designers will attempt to resolve these discrepancies with the agreement of both the Architect and Structural Engineer. This must be done prior to submitting the Shop Drawing to the Client for confirmation. The result shows the proposed method can improve the overall performance.

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