

An Optimizing Algorithm for Tower Crane Selection in Precast Concretes Structures Based on Cost in China

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Keywords: Precast Concrete (PC), tower crane, selection, precast rate

Abstract. Tower crane, transporting components vertically and horizontally, is the most expensive machine in construction site. In order to reduce cost and advance construction schedule, tower crane should be well located. Based on matlab platform, this paper generates an optimizing algorithm to selection optimal type and location of tower crane which is divided into three parts. 1) Tower crane selection model is built to define alternative type and location to establish crane. 2) Tower crane time mode is generated to calculate hoist time. 3) Tower crane cost model to find the optimal location and type of crane based on cost and precast rate. Then, a practical case, using this algorithm, is showed to demonstrate the outputs, and analyze the relationship of the cost and precast rate.

Introduction.

With the acceleration of construction industrialization in China, precast prefabricated construction, mainly using concrete (PC) structure technology, has been widely used among high-rise building [1]. Accounting for the development, component weight gradually rises which leads to higher requirements for tower crane. Furthermore, the operating efficiency of the crane not only concerns the construction cost and safety, but also controls the rhythm of construction schedule. In addition, tower crane is the most expensive machine in construction equipment [2,3]. In order to get the minimal cost, tower crane should be well located with proper type.

The study of tower crane optimal layout scheme began in 1999. P. Zhang et al. proposed that the lifting capacity determines the lifting radius of tower crane, and the crane must be located in the "Feasible Area" on accounting for the location of demand point. Then, they formulated tower crane hoist movement which constructed the foundation of later study [4]. In order to visualize the optimal scheme, J. Irizarry et al. introduced BIM and GIS to improve the method into the 3D perspective [5]. Other scholars applied many algorithms and mathematical method to optimal the tower arrangement, such as genetic algorithm, mixed-integer-linear programming (MILP), firefly algorithm et.al [6].

In these studies, researchers solved the optimal problem mainly focusing on the material stocking position, demand point location, hoisting time, tower crane number and coverage of the lifting but not considering precast rate. Z. Nadoushani and other researchers found that the location and type of tower crane is significantly affected by precast rate [1]. Therefore, this paper generates an

optimizing algorithm to find the optimal selection and location of tower crane and analysis the relationship of the cost and predicted rate.

An Optimal Algorithm of Tower Crane Layout Scheme.

Tower crane selection model

Tower crane should be well located to satisfy all demand components with the corresponding lifting radius. Accounting for the tower crane lift capacity, the lighter the components is, the larger the lifting radius is. In order to deliver components to their demand points, the crane should lay on the cross area.

Tower crane time model

Horizontal movement. When delivering the prefabricated components, the hoist movement of tower crane could divide into vertical movement and horizontal lifting movement according to Zhang et al. research. The crane, located on K (x_k, y_k, z_k) hoists components from material supply point S (x_s, y_s, z_s) to demand point D (x_d, y_d, z_d), and the horizontal motion consists of the linear motion of the trolley and the rotation of the jib. Eq. 1 to 3 calculate the distance among crane location, supply point and demand point. Then, the formulas calculating the time of the rotation of jib and the trolley motion are shown in Eq.4 and Eq.5 respectively. The total time required for horizontal movement can be computed by Eq.6 which combining Eq.4 and Eq.5 .

$$\rho_D^K = \sqrt{(x_d - x_k)^2 + (y_d - y_k)^2}. \quad (1)$$

$$\rho_S^K = \sqrt{(x_s - x_k)^2 + (y_s - y_k)^2}. \quad (2)$$

$$\rho_S^D = \sqrt{(x_d - x_s)^2 + (y_d - y_s)^2}. \quad (3)$$

$$T_\omega = \frac{1}{v_\omega} \arccos \left(\frac{(\rho_S^D)^2 - (\rho_D^K)^2 - (\rho_S^K)^2}{-2 \cdot \rho_D^K \cdot \rho_S^K} \right). \quad (4)$$

$$T_r = \frac{|\rho_D^K - \rho_S^K|}{v_r}. \quad (5)$$

$$T_h = T_r + T_\omega. \quad (6)$$

Where T_ω = time for trolley movement; T_r = time for jib rotation; v_ω = slewing speed of jib (rad/min); and v_r = radial speed of trolley (m/min).

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Vertical movement. The process of vertical movement is divided into two parts: vertical lifting movement and vertical descent movement. In order to ensure that no collisions occur during transportation, there would be a certain height h_0 between the bottom of component and the top of demand point when transporting. Eq.7 computes the time consuming of vertical lifting movement. Thus, this paper adds the formula to calculate the needed time of descent movement, as Eq.8 illustrates.

$$T_{v1} = \frac{|z_d - z_s| + h_0}{v_h}. \quad (7)$$

$$T_{v2} = \frac{h_0}{v_h}. \quad (8)$$

Where v_h = hoisting speed of hook (m/min)

Total travel time of crane. The calculation of the total time $T_{i,j,l}^o(x_s, y_s)$ for a component hoisting is shown in Eq.9.

$$T_{i,j,l}^o(x_s, y_s) = T_{v1} + T_h + T_{v2}. \quad (9)$$

Where i, j and l represent the order of lifting component, the floor of demand point and the order of demand point respectively.

Considering the total hoisting process, there would be unloading time T^u and waiting time T^w . Therefore, Eq.10 defines the total time of a hoisting scheme.

$$T_{t_n} = \sum_{i=1}^I \sum_{j=1}^J \sum_{l=1}^L T_{ijl}^o + T^u + T^w. \quad (10)$$

Where I, J and L refer to the total number of the same type components, floor and component type respectively.

Tower crane cost model

In general, the volume of concrete in a project is a constant value which determined in the design stage, so the larger the volume of prefabricated is, the smaller the volume of cash-in-place parts. However, the prefabricated components are transported by piece, the cash-in-place parts are delivered based on weight. Thus, the lifting time is distinct when the precast rate is different. As shown in Eq.11 the total cost C_t consists of the cost of component C_{pc} , the cost of cast-in-place parts C_c and the cost of tower crane C_h . The cost of tower crane is made up of tower crane installation and dismantle cost C_{in} , foundation cost C_f and rental cost C_r . Eq.12- 15 shows the way to calculate C_{pc} , C_c and C_h .

$$C_t = C_{pc} + C_c + C_h. \quad (11)$$

$$C_c = V_c \times C_{cu}. \quad (12)$$

$$C_{pc} = V_{pc} \times C_{pcu}. \quad (13)$$

$$C_h = C_{in} + C_f + C_r. \quad (14)$$

$$C_r = T_h \times C_{ru}. \quad (15)$$

Where V_{pc} and V_c refer to the total volume of prefabricated components and cast-in-place parts respectively, unit: m^3 . C_{pcu} and C_{cu} represent the civil construction cost of per cubic meter of prefabricated components and cast-in-place parts respectively. T_h refers to tower crane rental time, C_{ru} refers to the rent of tower crane per day.

Case Study

This case is the construction project of Chongqing Jianzhu College with thirteen floors in China. This project uses the attached tower crane. The tower crane can be selected for QTZ63, QTZ80 and QTZ125, and the lifting capacity of those cranes increases in order. This paper involved 14 different types of prefabricated parts, and analyzes the relationship between the cost and the precast rate.

Based on the "Shanghai Municipal Commission of Housing and Urban-Rural Development on the Assembly of Precast Rate of Construction Unit and the Assembly Rate Calculation Rules (Trial)",

$$\text{Precast rate} = \frac{\text{Concrete volume of precast parts}}{\text{cast-in-place parts} + \text{concrete volume of precast parts}} \times 100\%$$

In this case, the types of precast components are columns, beams, stairs and floors. The precast rate is changing through the combination of components. On account for using attached tower crane, the attachment route of the crane surrounds the building boundary with the distance of 4 meters, as shown in Fig. 1.

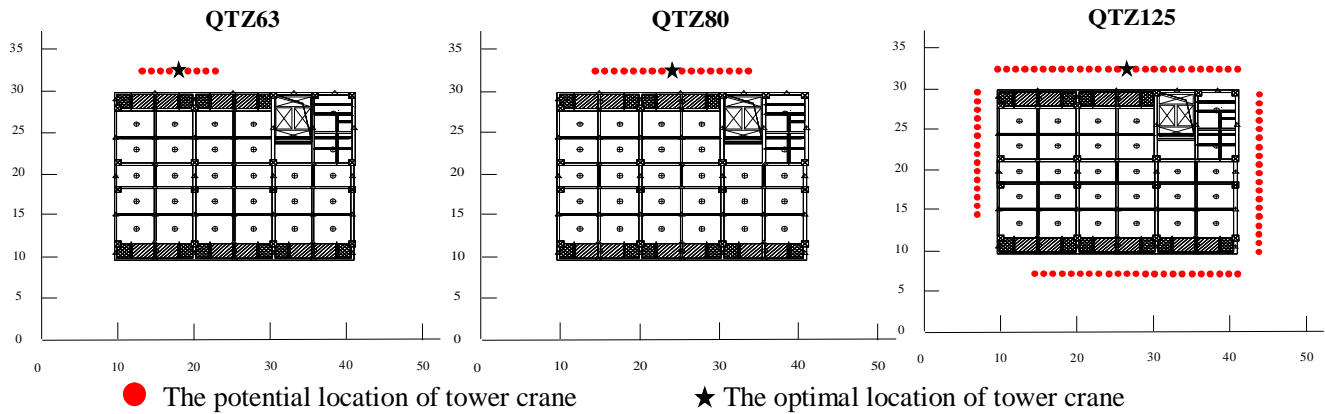


Fig 1. The possible and optimal crane location

Table 1 Cost of different tower crane in different precast rate

Number	Prefabricated Part	Precast Rate[%]	Prefabricated Volume [m ³]	Total Cost [1000 RMB]		
				QTZ63	QTZ80	QTZ125
1	S	3.29	115.70	4372.08	4383.27	4419.20
2	C	20.45	718.25	4522.87	4533.99	4569.64
3	S, C	23.74	833.95	4553.61	4564.74	4600.34
4	F	31.16	1094.28	4619.92	4631.03	4666.55
5	S, F	34.45	1209.98	4650.50	4661.61	4697.10
6	B	34.47	1210.63	4650.64	4661.76	4697.35
7	S, B	37.76	1326.33	4681.13	4692.25	4727.81
8	C, F	51.61	1812.53	4806.36	4817.41	4852.56
9	S, C, F	54.90	1928.23	4836.71	4847.76	4882.89
10	C, B	54.92	1928.88	4836.92	4847.98	4883.20
11	S, C, B	58.21	2044.58	4867.24	4878.29	4913.50
12	B, F	65.63	2304.90	4934.23	4945.26	4980.37
13	S, B, F	68.92	2420.60	4964.52	4975.55	5010.63
14	S, C, B, F	89.37	3138.85	5150.77	5161.73	5196.45

Note: S, C, F and B refers to stairs, columns, floors and beams.

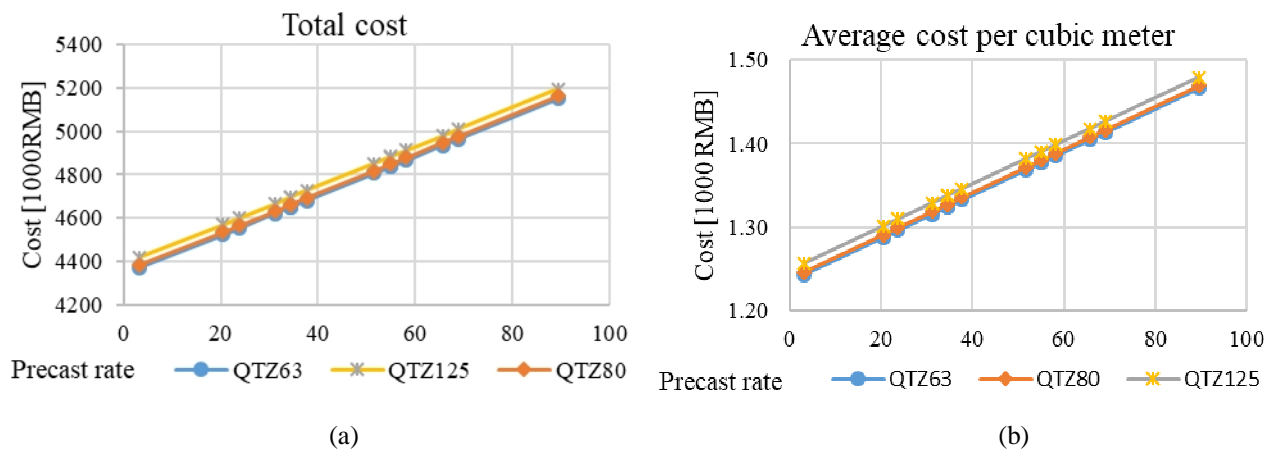


Fig.2 The total cost and average cost of per cubic meter of the case

Then, based on this case, some experiments have been carried out on matlab platform. By importing into the position and weight of the components of different precast schemes, the optimal location of the tower crane is the position that get the lowest cost with consideration of the performance

parameters of the crane. Then, this case analyzes the relationship between the cost and prefabricate rate by changing the types of prefabricated components, as shown in Table 1. The relationships between total cost and precast rate is shown as Fig.2 (a), and the relationships between total cost and precast rate is shown as Fig.2 (b). Both of them has an positive relation with the precast rate of the precast scheme which exhibits an approximate linear correlation.

Conclusions

In order to realize minimal cost, this paper has generated an algorithm for optimizing the selection and location of tower crane with the consideration of the performance parameters of tower crane and the attribute of components, including tower crane selection model, tower crane time model and tower crane cost model.

Based on the algorithm and actual case, this paper analyzes the relationship between the cost and precast rate. The different precast rates are formed by combining the different PC components. After several experiments, it was found that the total cost had an approximate linear correlation with the precast rate of the precast scheme. Although lower precast rate lead to lower cost, concrete (PC) structure technology is greener and faster than cast-in-place concrete. Thus, it is necessary for designer to find the optimal solution of cost and precast rate.

Acknowledgements

This work was financially supported by the Fundamental Research Funds for Central Universities (106112016CDJXY030002) and the City Science (Integration and demonstration of key technology research of prefabricated housing construction, 2015 No. 0-1).

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