Analysis of Parameterized Duration Model Based on Reverse Flowline Pace

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Abstract. When the actual project adopts the traditional flow construction method to organize the flowing construction of different steps and beats, there are usually defects such as longer planned duration, or the dominant construction process cannot be operated continuously between the layers. In order to effectively solve the above problems, based on the definition expression of flowing duration, the key constraint of organizing flowing construction is considered, the meaning of flowline pace is redefined, and the concept of reverse flowline pace is introduced, and then the parametric duration model is reconstructed. Finally, the implementation effect of the improved duration model applied to schedule planning is analyzed by taking the standard layer of an actual project as an example. The results show that: the improved duration model has the same constructive composition with the definition form of traditional flowing duration, which can easily update the corresponding theoretical knowledge points of flowing construction in the existing textbook of Civil Engineering Construction, and the optimization application based on the parameterized duration model can achieve the effect of the optimal integration of the duration and resources, and the shortening of the duration and the increase of the cost can be quantitatively analyzed and evaluated.

Keywords: Construction of civil engineering, flowing construction, different steps and beats, flowline pace, duration model

1 Introduction

Flow construction is one of the most scientific construction organization methods in the field of modern construction management, and has been widely used in various types of engineering construction. Numerous engineering practices have shown that the scientific and reasonable application of flow construction method can realize the comprehensive benefits of balanced supply of resources, effective shortening of construction period and professionalization of construction quality. The classic textbook of civil engineering construction introduces the basic principles of flow construction [1-3], such as the basic concept of flow construction, flow parameters, and flow or-

G. Zhao et al. (eds.), *Proceedings of the 2024 7th International Symposium on Traffic Transportation and Civil Architecture (ISTTCA 2024)*, Advances in Engineering Research 241,
https://doi.org/10.2991/978-94-6463-514-0_44

ganization methods. Among them, the flowline pace, as a basic flow parameter and also an indirect parameter, plays an important role in the organization process of flow construction and the realization of schedule benefits, and has been a research focus of flow construction principles [4-7].

There are two traditional definitions of flowline pace: one is the minimum and reasonable time interval (excluding breaks and overlaps) for construction teams of adjacent construction processes to enter the same construction section successively to start construction [2], and the other is the minimum and reasonable time interval (excluding breaks and overlaps) for construction teams of adjacent construction processes to enter the site successively [3]. And it should be noted that, when organizing multiply-beat flow construction, all the flow steps are equal is one of the important characteristics of this kind of flow construction, which is also the consensus of the building construction industry. However, based on the first definition is obviously contradictory to this characteristic, so the second definition has been gradually recognized by the academic and engineering communities. According to the second definition, the meaning of "minimal and reasonable" is characterized by the following features: (1) Maximum continuous operation of construction crews; (2) Parallel lap construction of adjacent construction processes wherever possible; (3) Continuous utilization of work surfaces wherever possible. If a fixed-beat flow construction is to be organized, the above characteristics can be ideally represented for the case of non-layered construction, whereas in the case of layered construction additional consideration needs to be given to the limitation of the number of construction sections. The above characteristics do not perform well if the construction is to be organized in flow construction with different steps and different beats. In the case of non-layered construction, the duration is relatively long and the working surface is idle for a long time if continuous operation of crews is considered, as shown in Fig. 1. In the case of layering, even the flow condition of "continuous operation of the dominant construction process" cannot be satisfied [1-3], as shown in Fig. 2. Engineering practice generally seeks to shorten the construction period, and a common method is to locally adjust the in-layer construction status of those secondary construction processes based on the results of Fig. 1, as shown in Fig. 3, but this adjustment lacks a theoretical basis. Eq. (1) is the expression defined in the classical textbook for the flow duration, however, the flow duration and the total flow step obtained according to Fig. 3 cannot be calibrated by Eq. (1).

$$T_L = \sum K_{i,i+1} + T_n + J - D \tag{1}$$

Where the $K_{i,i+1}$ is the sum of the flow steps, the T_n is the duration of the final construction process, the J is the sum of all intervals, and the D is the sum of all overlaps.

In other words, when a multi-storey building is organized the flow construction with different steps and different beats, due to the lack of key theoretical support, engineers can only rely on their experience to arrange the time of entry of crews and the time of interruption of operations between construction sections.

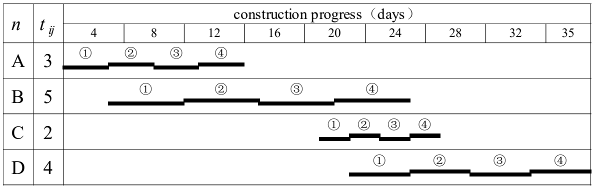

Fig. 1. Gantt chart of flow construction without layering

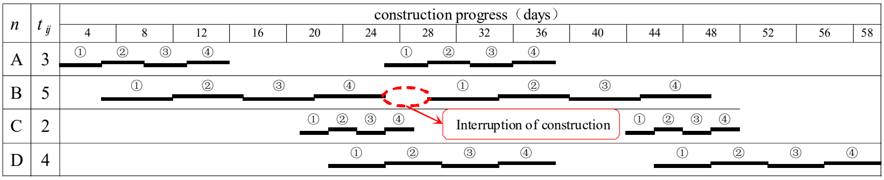

Fig. 2. Gantt chart of flow construction in layering

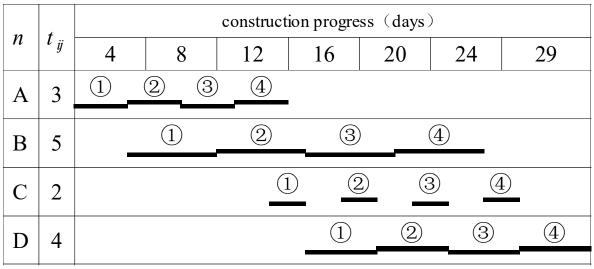

Fig. 3. Gantt chart of adjusted flow construction without layering

2 Parameterized Duration Model

2.1 Key Condition

When organizing flow construction, five basic conditions need to be considered [3]: (1) the project object is divided into construction processes with technical characteristics; (2)the project object is divided into construction units with spatial characteristics; (3) each construction process is arranged for independent teams; (4) adjacent construction processes as far as possible to achieve parallel lap construction state; (5) the leading construction process must be a continuous operation. Among them, conditions (1) and (2) belong to the prerequisites for organizing the flow construction, conditions (3) and (4) are the followers of conditions (1) and (2), respectively, while condition (5) is an independent condition.

When the first four conditions mentioned above are satisfied, it is possible to organize the flow construction with different steps and different beats, which has two typical characteristics: that is, the utilization of the working surface will certainly appear to be idle; the team can work continuously within the layer, but it is inevitable that the phenomenon of nesting occurs when the layer is overloaded. In the case of layering, it is possible that all construction processes are discontinuous, as shown in Fig. 2, which conflicts with condition (5), and thus condition (5) is surely the key condition to ensure that the flow construction can be organized efficiently. Certainly, the continuity of teamwork and the continuous utilization of working surfaces, as well as a balanced and rhythmic supply of resources, need to be taken into account as far as possible.

2.2 Key Parameter

To simplify the parametric analysis, the lap (t_d) can be defined as a negative interval based on the nature of the effect on the utilization of discontinuities on the working surface. In the process of preparing the flow construction schedule, flow parameters such as the number of construction processes (n), the number of construction segments (m), the construction layer (r), the flow beat (t_{ij}), the total interval within the layer (Z_i) , the interval between layers ($Z_{i,i+1}$) can be determined directly[4], in which the total interval within the layer (Z_i) can be calculated by equation (2). The flowline pace ($K_{i,i+1}$), on the other hand, needs to be determined indirectly by other parameters according to the characteristics of the flow organization mode. Only then can the key aspect of schedule preparation be carried out, which is to determine the entry time of each construction team in turn. Therefore, for this type of flow organization, the flowline pace is a key parameter for the preparation of the schedule and the determination of its duration model, regardless of whether or not construction layers are to be considered.

$$Z_i = \sum t_j - \sum t_d \tag{2}$$

Where $\sum t_j$ is the sum of all intervals in the layer and $\sum t_d$ is the sum of all laps in the layer.

In the organization of flow construction, the role of flowline pace is to ensure that the construction team in the layer of work as continuous as possible under the premise of maximizing the realization of parallel construction between adjacent construction processes. That is, once the construction team enters a certain construction layer, it starts to work continuously. Yu Lijun [3] defined the flowline pace as the smallest and reasonable time interval (excluding intervals and overlaps) for adjacent construction teams to enter the construction site successively when organizing the flow construction. Eq. (3) is a calculation method for determining the flow step on the premise of considering continuous operation of teams, but in the practical application of the tiered case, the defects shown in Fig. 2 may occur.

$$K_{i,i+1} = \begin{cases} t_i & t_i \le t_{i,i+1} \\ mt_i - (m-1)t_{i,i+1} & t_i > t_{i,i+1} \end{cases} \tag{3}$$

In order to solve the above problems, this paper proposes two amendments: one is to appropriately adjust the meaning of "minimum and reasonable" in the definition of flowline pace, which means that the premise based on the continuous operation of the team can be changed or expanded to be based on the continuous utilization of the work surface if necessary; the other is to introduce the parameter of reverse flowline pace, which is the smallest and reasonable time interval (excluding intervals and overlaps) for adjacent construction teams to exit the construction site successively (denoted by $K_{i,i+1}^{-1}$). When there are N teams, the number of reverse flowline pace is N-1, and its calculation principle is consistent with the flowline pace, but the calculation direction is opposite.

Thus, in the process of organizing the flow construction, the basic model of the schedule plan is established based on the premise of continuous utilization of the working surface as shown in Fig. 4, which shows that the positive flowline pace (that is, the traditional flowline pace) and the reverse flowline pace can be calculated in accordance with Eqs. (4) and (5), respectively, and it is obvious that the main information of the schedule plan shown in the diagram, such as the duration and the continuity characteristics, etc., is consistent with the constraints on the key conditions as mentioned before.

$$K_{i,i+1} = t_i \tag{4}$$

$$K_{i,i+1}^{-1} = K_{i+1,i} = t_{i+1} \tag{5}$$

Where t_i is the flow beat of the ith construction process and t_{i+1} is the flow beat of the i+1th construction process.

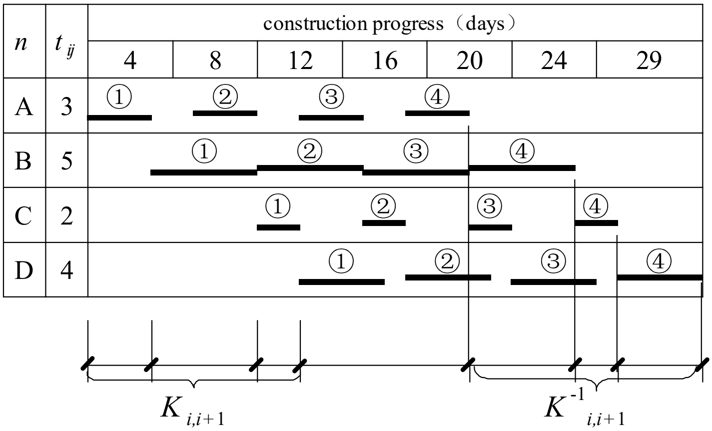

Fig. 4. Schedule planning model based on continuous utilization of working faces

2.3 Duration Model

After redefining the meaning of flowline pace and introducing the parameter of positive flowline pace, comparing Figures 3 and 4 shows that they have the same duration. Fig. 4 expresses two conceptualized models of the meaning of positive and the reverse flowline paces, while Fig. 3 shows the actual application of the schedule model, which is based on the premise of continuous utilization of the working face to achieve the maximum degree of continuity of the work teams, as well as the maximum degree of parallel overlap between the construction processes.

If Eq. (2) is substituted into Eq. (1) and the duration T_n of the final construction process is adjusted to the total operating time T_N of the final incoming construction crew, the expression for the running duration is re-obtained, see Eq. (6).

$$T_L = \sum K_{i,i+1} + T_N + Z_1 \tag{6}$$

Where $\Sigma K_{i,i+1}$ is the sum of positive flow steps, T_N is the total operating time of the last incoming construction crew, and Z_1 is the algebraic sum of all intervals and laps in the first layer.

As seen in Eq. (6), the flow schedule model consists of three components: flowline pace, interval, and the operating time of a particular team, so Eq. (6) can also be varied theoretically into the form of Eq. (7) and Eq. (8).

$$T_L = \sum K^{-1}_{i,i+1} + T_1 + Z_1 \tag{7}$$

$$T_L = \left(\sum{}^{*}K_{i,i+1} + \sum{}^{*}K^{-1}_{i,i+1}\right) + T_{\max} + Z_1 \tag{8}$$

In the formula, T_l is the total operation time of the earliest incoming construction team, T_{max} is the total operation time of the dominant construction team, $\sum K^{-1}_{i,i+1}$ is the sum of the reverse flowline paces, $\sum{}^{*}K_{i,i+1}$ is the sum of the part of the positive flow water steps before the dominafnt construction team enters the site, and $\sum{}^{*}K^{-1}_{i,i+1}$ is the sum of the part of the reverse flowline paces after the dominant construction team retires from the site, and the significance of the other symbols is the same as the previous one.

It should be noted that when the meaning of positive and the reverse flowline paces in this paper is adopted, both Eq. (6) and Eq. (7) obtained based on the traditional duration model are defective, as shown in Fig. 4, the beginning and end of the two construction crews have the problem of idleness, whereas the calculation result of applying Eq. (8) can satisfy Fig. 3 and Fig. 4 at the same time, and meets the key conditions of the flow water construction.

Further, after substituting Eqs. (4) and (5) into Eq. (8), a more concise duration model can be obtained, see Eq. (9).

$$T_L = \left(\sum t_i - t_{\max}\right) + T_{\max} + Z_1 \tag{9}$$

In the formula, tmax is the flow beat of the dominant construction process, and other symbols have the same meaning as before.

3 The Case for Flow Construction Organization

A project is organized in accordance with heterogeneous step-by-step and beat-by-beat flow, and the standard layer consists of construction processes A, B, C, D, E, F, and G, including 4 construction sections, and the flow beats of each construction process are 2, 4, 3, 5, 2, 4, and 3. There is a 2-day technological break, which exists between construction processes B and C, and there is a 1-day organizational overlap, which exists between construction processes C and D.

The duration obtained based on Eq. (9) is 36 days, while the result based on Eq. (1) is 45 days, it can be seen that the application of the optimization method in this paper makes the duration shorten by 9 days, which is a reduction of 20%.

Fig. 5 shows the schedule obtained according to the traditional flowing schedule model with a duration of 45 days. Fig. 6, on the other hand, shows the schedule obtained according to the parametric schedule model proposed in this paper, with a duration of 36 days, which takes into account the principle of schedule optimization. Further, the principle of integrated optimization of duration and resources is executed, that is to say, the discontinuous time of shift operations is compressed as much as possible, and the optimized crosswalk diagram is obtained as shown in Fig. 7.

Fig. 6 reflects that the purpose of organizing the overlap parameter between C and D is to arrange the D team to enter the site earlier to apply the first construction section in order to shorten the construction period, and the subsequent construction sections can be disregarded without considering the overlap relationship. And the total time of discontinuous operation of crews in Fig. 6 is 9 days, which is exactly equal to the difference of duration reduction calculated according to Eq. (9) and Eq. (1). Therefore, a further conclusion can be obtained, that is, without considering the premise of intermittent and overlapping, the optimal duration reduction value calculated according to (9) is the discontinuous time of crew operation, which is not only the target of the initial crosswalk optimization, but also can be used as an evaluation index for the comprehensive benefit analysis of the duration reduction and cost increase.

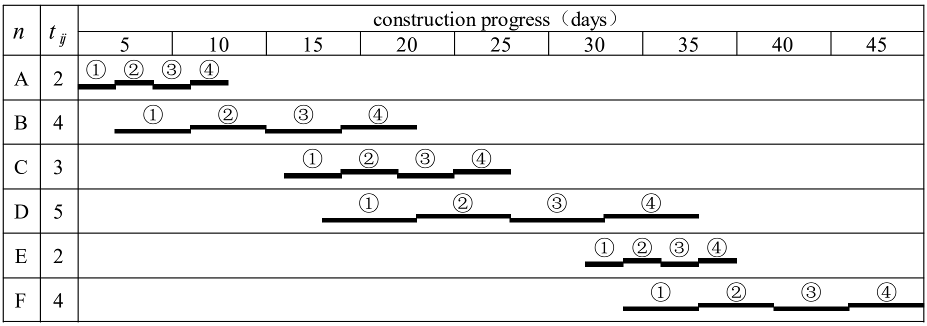

Fig. 5. Gantt chart based on traditional duration modeling

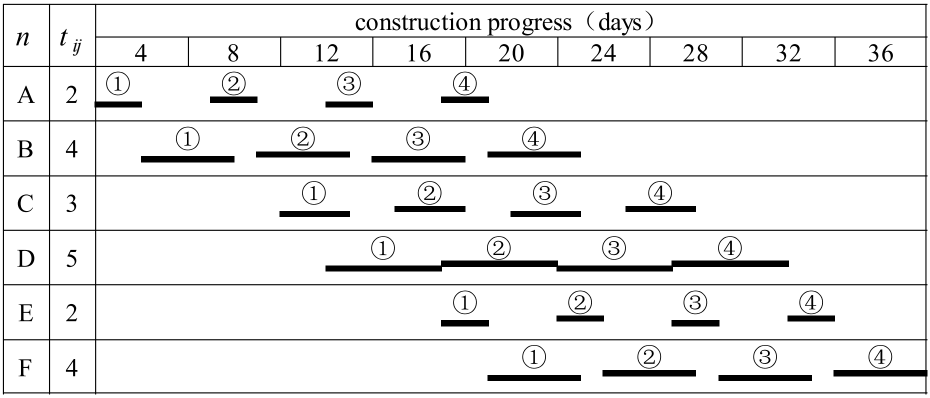

Fig. 6. Gantt chart based on parametric duration modeling

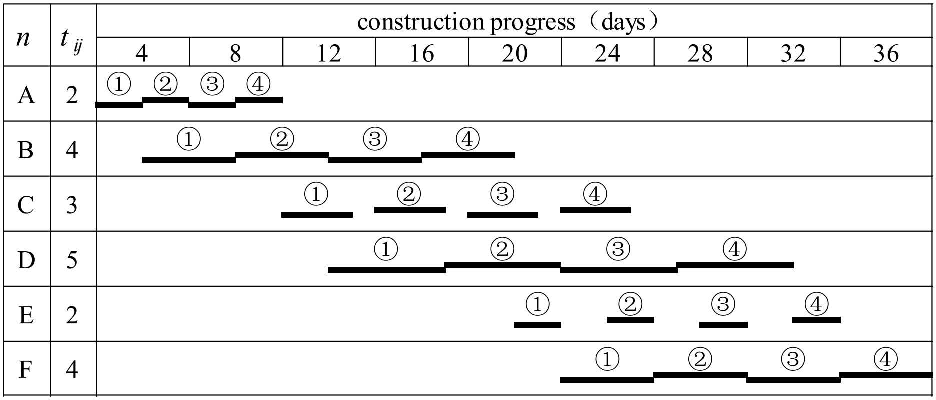

Fig. 7. Gantt chart based on the principle of combined optimization of duration and resources

4 Conclusion

Without changing the specific calculation method of running water parameters, this paper redefines the meaning of flowline pace based on the goal of optimal duration and introduces the positive flowline pace, which in turn establishes a new concise calculation expression for running water duration.

Combined with an example of the flow construction organization with different steps and different beats shows that the new flowline pace proposed in this paper can achieve the shortest duration and its quantitative optimization goal, which not only improves the theoretical knowledge about flow water construction in the existing traditional textbooks, but also adopts the construction organization methods and ideas in the examples that can be directly applied to engineering practice.

Acknowledgements

The research described in this paper was sponsored by teaching and research projects of the department of education of Anhui Province (2021jyxm0612, 2020zdxsjg159, 2020jyxm0791, 2020xsxxkc225), scientific research projects of the department of education of Anhui Province(2022AH051860), scientific research projects of the department of housing and construction in Anhui Province(2023-yf089).

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