SIMULATION OF CONSTRUCTION PLANNING OR HIGH-RISE RC BUILDINGS A PROCESS PLAN CONSIDERING OVERTIME WORK

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Abstract: The study is aimed at better planning the cycle process that considers production characteristics in high-rise RC building construction and at establishing a better method by a simulation system using computer-aided tools. A special emphasis of this study is placed on examining the effect for shortening the cycle term of site works and the influence from overtime work on the productivity where situation of such real projects is taken into consideration. Furthermore, we examine choices of optimal working patterns even considering some additional labor cost generated by overtime work.

Keywords: High-Rise RC Building, Simulation, Cycle Term, Line Balancing, Resource Leveling, Overtime Work

1. INTRODUCTION

There are a variety of practical methods applicable to the process-planning phase of construction work. An increasing trend in developing construction work plans to consider the repetitive type of work, where the site work requires repetitive application of the same work process, particularly in such aspects as the need to suit the high-rise building construction or the mass construction of housing complexes. Besides, attempts to intentionally increase the repetitive cycles by segmenting the project sites for such purposes as boosting productivity and realizing shorter layoff periods for field workers. As compared with other types of construction work, the repetitive type of process by nature can be seen as readily subject to those production planning methods being widely used in manufacturing industries, making it possible to more systematically plan and execute the construction work.

With a simulation system for better planning and managing the work and processes of construction projects using a computer-aided support tool, this paper is aimed at establishing a method of systematically improving construction planning activities in high-rise RC building construction work for developing multiple dwelling-type housings.

Conventional studies over the process planning activities for high-rise building construction work have been based on actual data collected from the established “regular work schedules,” that is, man-hour data accumulated only between the daily starting time through the closing time. So far, few case studies has been made covering “early bird extra work” and “evening overtime work,” which are often needed on the first-line worker levels trying to “adjust” their daily work volume as such. In this study, by considering such on-going work-site realities and incorporating such overtime work data as aforementioned, the authors intend to look at the process improvement phase by means of an evaluation index in terms of the effect of shortened work cycles and degrees of productivity fluctuation. More specifically, this entails 1) a review to set the timing as to when to change the construction cycle term for the basic-floor construction work-cycle on the premise of the production characteristics of the type of construction project, and 2) evaluation of decision-making possibility as to selection of field work patterns.

2. PROCESS SIMULATION SYSTEM

2.1 Functions of the Process Simulation system

The system being introduced hereunder is a construction system simulation system by which the process to reduce time span needed for the any standard floor pattern work-cycle can be logically calculated electronically. It considers on-going quantitative changes in required materials and the accumulating learning effect. Also, it has a process-adjusting function that purposely incorporates overtime work. It can also evaluate the work plan through use of such data as balance loss and indices of working smoothness and leveling of labor fluctuation. Further, it compares ups and downs in the total construction schedule and total labor cost, so as to determine priorities for either schedules or labor cost aimed at realizing an optimum process plan.

2.2 Simulation System Structure

The software used in our basic system is MS Excel for the spreadsheet program, combined with MS Project as the project management software. As shown in Fig. 1, its nucleus is a database covering information about construction materials to be used, specific work items and required workforce. Visual Basic for Applications software is used in automating spreadsheet operation.

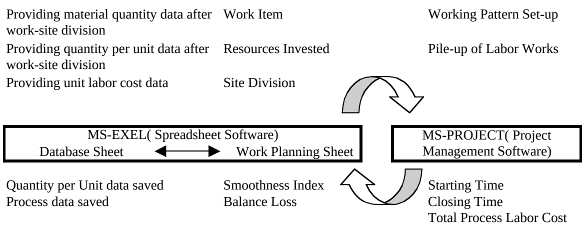

Fig. 1 The Structural Sketch of the Simulation System

2.3 Establishing Constraint Conditions

The basic regular daily working hours is set at 8 hours, being allocated for 4 time-units of 2 hours each (i.e. a one-quarter day work-unit). Also, a maximum of 1 hour per day of overtime work is allowed. Specifically, early-bird overtime can be scheduled between 7 to 8 a.m. or a dusk overtime between 5 to 6 p.m. The daily regular work period is set at 8 hours a day. A maximum of 1 hour per day can be allowed as overtime work, which should fall under one of the following four patterns:

Pattern I: Regular work during the scheduled 8-hour period

Pattern II: Overtime for 1 hour per day by a molding worker

Pattern III: Overtime for 1 hour per day by a reinforcing bar placer

Pattern IV: Overtime for 1 our each by both a molding worker and a reinforcing bar placer

Evaluation of the process involving different Patterns is done in terms of the additional labor cost necessitated by the reduced number of work-days of the cycle term and the needed overtime work. To specify the work-to-work connections, an accurate state of on-going works is demonstrated by combining the use of 1) the pile-up type "finish-start" (FS or a work started upon finish of the previous work) link and the "start-start" (SS or a work started along with the start of the previous work) and of 2) the allocation type "start-start (SS) + "lag-time" set-up. Also, another restraint is imposed on the concrete work to be definitely complete the concrete-placing work in one day.

2.4 Simulation Flow

2.4.1 STEP 1: Developing the Database

Fig. 2 shows the flow of this Simulation System.

A number of database sheets to be used in each segment of site work are developed in this step. Data for [Materials Quantity Sheet] is produced for each part of the required work, where quantity units to be used are determined according to the Building System as a mixture of the physical contents of the building with their corresponding work methods. Also, when the work-site is divided, each segment is set up with the materials to be used there. [BUGAKARI-setting Sheet (Unit Quantity-setting Sheet)] shows the trend of Unit Quantities based on the learning curves that were derived from Work Measurement. It can be determined according to the selected floor, Unit Quantity on that floor, and the degree on the Learning Curve. Data on the [Resource Sheet] establishes Worker(s) as "Resource Names" and Standard Labor Cost of each named worker.

2.4.2 STEP 2: Work Plan

The [Initial Set-up Screen] sheet determines such factors as "forecast conditions of the object floor," "number of work area segments," "segment-to-segment work connections," and "work characteristics of each work segment." Specific information about Work Characteristics such as "Serial Work Number," "Outline Number," "Part of Work Section," "Name (description) of Work," "Preceding Work," "Work Connection," "Crane Need," "Yard Work Need," "Related Job Titles," "Number of Work-team Members," and "Number of Work-teams" are manually entered. Such factors as Project Name, Number of Segment of the Work Section, Segment- to-segment Connection," (indicating the starting time for the next work section), and Forecast conditions of the Object Floor (Start and Finish)," are specified. Then, information about all work items per floor to be worked on, work characteristics of each work item, data from "Material Quantity sheet" and from "Unit Work Quantity," are shown on the screen (all in line with the set-up status of Labor Database and Work Characteristics sheet). This should automatically provide estimated length of Work-time. Then, the data is visually "redesigned" so as to permit easier import with the Project Management software. The completed sheet is now kept on file.

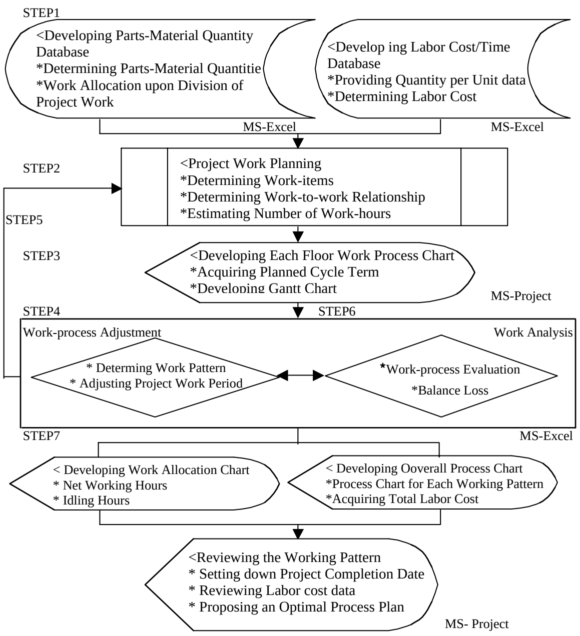

Fig. 2 Simulation Flow Chart

2.4.3 STEP 3: Preparing Work-process Chart for Each Floor

Here, the Database sheet completed with spreadsheet software is imported to Project Management software, where specific Work Period for each floor is automatically figured out. Also, Staring/Closing Hours and project's Labor Cost data are obtained, and the final data is kept on file as spreadsheet. Process chart for each floor is automatically produced and filed as a Project Management file. The daily calculation of Labor Cost here is rendered in terms of workers' hourly pay.

2.4.4 STEP 4: Work-process Adjustment

Along with the calculation being performed during Step 3, Loss Time in each "between-works interval" too is figured out. If any improvement action becomes necessary based on the loss time data obtained, a return to Step 2 becomes necessary so that the conditions of between-works inter-dependency (in terms of Lag Time) is automatically altered, and a new process planning is made with the basic floor. The same routine is repeated from the ground floor to the top floor. Finally, the cycle term applicable to each floor is determined with specific start/close hours and related labor cost data figured out.

2.4.5 STEP 5: Work-process Planning

This step includes a return to Step 3 where four working patterns can be established based on the combinations of work for molding workers and reinforcing bar placers on the Main Menu of the Project Management software. Also, labor cost data such as Unit Labor Cost and Work can be re-entered directly on the screen. With specific working patterns determined, the system now automatically figure out the total project work period and labor cost along with the material/labor database and the specific Work Characteristics set-up information.

2.4.6 STEP 6: Work-process Evaluation

In evaluating any work-process, the common practice is to use the data of the number of days required and productivity (such as unit quantity). The system we are discussing is unique as it applies two types of index as being used among manufacturing circles: 1) [Balance Loss] that indicates to what extent the work arrangement contains idle or non-productive time elements, and 2) [Smoothness Index] that reflects uneven work-hours. Even if the work-process contents show gradual changes because of reduced materials or of some learning effect, the system can count the number of idle-hours through obtaining Balance Loss information.
Balance Loss is mathematically expressed as follows:

$$BL_{ij} = \frac{\sum_{k-1}^{n}(c - t_{kij})}{nc} \times 100$$

Here, a = number of work stations, c = number of cycle hours, t_k = total working hours on the k_{th} working day (i.e. aggregate total of all element hours).
Smoothness Index is mathematically expressed as follows:

$$SI_{ij} = \sqrt{\sum_{k-1}^{n}(t_{maxij} - t_{kij})^2}$$

Here, t_{max} is maximum working hours on the day [n], as resulted from allocation of work elements. Finally, this step graphically displays on-going trend of Balance Loss and Smoothness Index for all stories as well as by work-sections and by job-titles.

2.4.7 STEP 7: Analysis of the Final Results

Aimed at making the task of work-process management easier, this system compares work-hours between the materials used, analyzes the learning effect, and make the results visible in several ways: “Process Evaluation Graph,” “Work Allocation Chart,” “Table of Total Process Labor Cost,” ”Overall Process Table,” and “Work-process Planning Table for Each Working Pattern.” These means help identifying to what floor is best for moving in and for what job titles should the process improvement best address.

3. **SIMULATION APPLIED TO ACTUAL BUILDING CONSTRUCTION**

Based on the actual data accumulated in the system, the construction process of the basic floor is simulated so as to validate and analyze the system itself in specifying 1) the effect of reducing the cycle term for each of the four Work Patterns; 2) process evaluation in terms of labor cost increase/decrease for overtime work; 3) process evaluation as reflected in Balance Loss and Smoothness Index; 4) evaluation of optimum planning of work-process.

Table 1 is a summary of the construction work of a high-rise multi-dwelling RC building as applied by our simulation system. The work represents a system construction as an improved type of the conventional method of construction work. The simulation treated those work items as found “on a group-work level,” dealing with a total of 34 items, the breakdown of which is: 1) 19 items of molding work per work segment; 2) 8 items of steel bar placing work; 3) 2 items of pressure welding; 4) 2 items of scaffold worker; 5) 3 items of earth work (see Table 2). Generally speaking, construction work of high-rise RC buildings consists of joint-works among workers with a number of different job-titles that is a relay of work from molding, steel bar placing, facility/plumbing work, through concrete work. In studying the work under this system, we intended to make the connections among the related works in the actual construction process well reflected. Specifically, the molding work is treated with its [Setting out] through [Floor mold insert] steps as one “bunch of works,” and the steel bar work with its [steel beam crane and set] through [steel pillar crane and set] steps as another “bunch of work,” for which the 1/4-day unit time is allocated appropriately. Fig. 3 illustrates the 7-day cycle term of such work processes. To help the actual construction process reflected better, drawing issue, rate of learning curve, actual quantity of materials and work unit for the intended cycle term are used. As for the ratio on the learning curve, the data of certain similar precedent case was considered. The Unit Labor Cost is calculated based on the published public labor cost data: Using its standard labor cost (daily rate), Unit Overtime Labor Cost per Hour is calculated as [Daily Unit Labor cost /8 x 1.25]. The simulation applied to the basic floor construction process based on the data of material quantities, unit labor cost and BUGAKARI (quantity per unit), and rates on the learning curves has resulted as follows.

Table 1 Construction Project Outline

Location	Minato-ku, Tokyo
To be used for	Multi-dwelling type housing
Total construction Peiord	April 1, 1998 ~ November 15, 2000
Architectural structure	RC
No. of floors	32 floors + 1-fl. basement + 1 tour-house
Total space of the cite	6,177.41m^2
Building ground space	2381.02 m^2
Aggregate floor space	38,999.13 m^2
Maximum height	99.5m
Construction Methods	Pillar・beam:frame: Simplified system
	Pillar・beam:steel bar welding: Automatic gas pressure-welding:
	Floor: steel bar built-in steel deck floor
	Balcony & misc.: Half PCa
	Concrete: Strength (mx)24~54N/mm^2, concrete placing by pump
	No. of Work-site divions: 2
Use of Cranes	Tower cranes: 2 units (120 tons)

Table 2 List of Work-items used in the simulation

Frame-molding work	Beam & floor/Frame/Fastening	Beam/Steel bar/Drop set
Total structure/Molding frame/Setting out	Floor/Frame/Stepped frame	Floor/Steel bar/Bar arrangement
Pillar/Frame/Build-up	Floor/Floor support/Unloading	Pillar/Steel bar/Crane & set
Pillar/Frame/Fastening	Floor/Floor support/Unloading	Beam/Steel bar/Unloading & Field pre-assmbly
Beam/Beam support/Crane	Pillar/Frame/Unloading & disassembly	Pillar/Steel bar/Unloading & Field pre-assmbly
Beam/Frame/Crane & set	Beam/Frame/Unloading & disassembly	Erection&Scaholding
Beam/Beam support /Set	Pillar/Frame/Preparation	Total/net/climbing
Floor/Floor support/Crane & set	Beam/Frame/Preparation	Stair/Stell frame/Setting
Floor/Frame/Crane & set	Steel bar work	Concrete placing
Floor/Frame/Insert	Pillar/Steel bar/Hoop bar finish	Total/Concrete/Molding to joint between work-site divisions
Balcony/PCa/Temporary setting	Beam/Steel bar/Crane & sedt	Total/Concrete/Preparation for placing
Balcony/PCa/Welding	Beam/Steel bar/Binding the pressure-welded part	Total/Concrete/placing

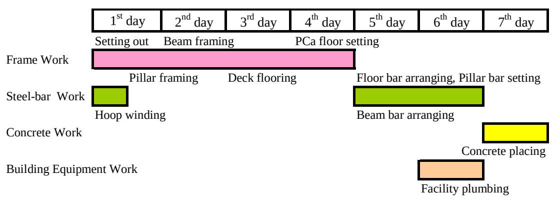

Fig. 3 Cycle Term Process

Fig. 4 represents the result of simulation of the cycle term for each work pattern. In each case, the cycle term is seen as reduced due to learning effect and other causes. Fig. 5 & 6 are cases of the cycle terms at the 25th & 28th floors with each work pattern. In consideration of lunchtime recess and other scheduled rest-time at the construction site. The time allocation by 1/4 day unit is used within the regular 8-hour work schedule.

Table 3 Labor Work & Cost Data

Type of Work	Learning Ratio (%)	Average Daily Attendance (Person)	Unit Labor Cost (¥/person/day)	Unit Overtime Cost (¥/person/hour)
Framing Work	85	15	19,200	3,000
Steel Bar Work	85	12	18,900	2,900
Scaffold Work	95	8	18,400	2,800
Concrete Work	95	8	18,600	2,900

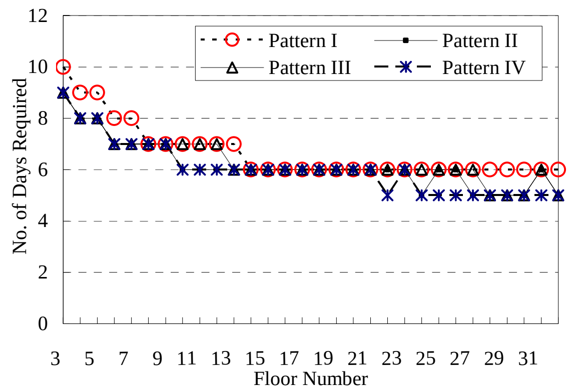

Fig. 4 Cycle Term by Different Work Pattern

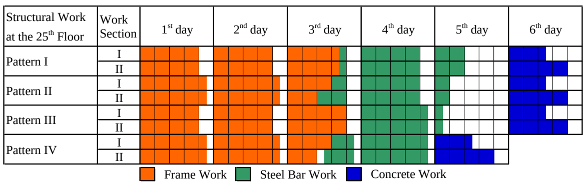

Fig. 5 Allocations of Work Segments at the 25th Floor

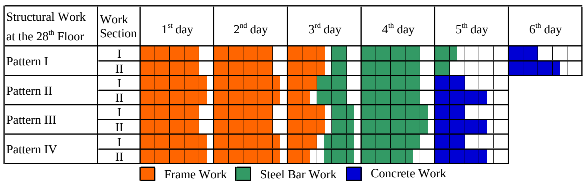

Fig. 6 Allocations of Work Segments at the 28th Floor

In the case of the work on the 25th floor, the cycle term by Pattern I is 6 days, as well as by Patterns II and III. The cycle term for Pattern IV, however, can be apparently reduced to 5 days. In the case of the 28th floor, the cycle term for Pattern I is 6 days. The cycle term for Patterns II, III and IV can by all means be reduced to 5 days because the overtime work largely make the steel bar work and the concrete work to come closer with each other. In other words, with molding workers or steel bar workers doing overtime for 1 hour, concrete workers' idling time can be well reduced. It is found that the cycle term can be reduced as a result of effective utilization of workers' increased working hours. The simulation applied to each Work Pattern resulted in considerably reducing the number of necessary workdays when compared with 200 scheduled days for Pattern I as follows:

Pattern II: 186 days (14 days saved)

Pattern III: 190 days (10 days saved)

Pattern IV: 191 days (9 days saved)

Incidentally, there were some "temporary ups and downs (plus & minus)" in these patterns as affected by temporary ups and downs in material supply. Data on Table 4 shows such plus/minus Figures as reflected in "Required Number of Cycle Term Days," "Cycle Balance Loss" and "Labor Cost-Plus/Minus (unit: ¥10,000)," respectively.

Table 4 Workdays Required & Cycle Balance Loss & Labor Cost Increase/Decrease

Floor	Workdays Required				Cycle Balance Loss				Labor Cost Increase/Decrease (Unit: ´10,000)		
	I	II	III	IV	I	II	III	IV	II	III	IV
3F	10	9	9	9	7.98	4.30	1.96	7.88	-11.6	-5.3	-7.4
4F	9	8	8	8	8.33	3.04	1.47	6.94	-2.0	-5.3	2.3
5F					11.50	6.46	4.80	10.12	-13.1	-5.3	-8.9
6F	8				9.64	0.88	1.82	5.61	6.0	-6.7	10.2
7F					12.24	5.33	4.67	9.50	6.0	-6.7	10.2
8F		7	7	7	3.07	8.21	7.50	12.25	6.0	4.2	10.2
9F					3.10	8.44	7.72	12.28	6.0	4.2	10.2
10F	7				8.60	13.57	13.96	3.15	6.0	4.2	-0.7
11F					10.42	2.17	14.14	7.81	-14.6	4.2	-11.8
12F					12.14	3.69	15.80	8.43	-14.6	4.2	-11.8
13F					11.22	2.10	0.51	6.08	-14.6	-6.7	-11.8
14F				6	0.97	6.91	4.65	10.12	-5.1	2.8	-2.3
15F					2.43	8.27	6.05	11.42	-5.1	2.8	-2.3
16F					3.75	9.49	7.31	12.59	-5.1	2.8	-2.3
17F					5.87	10.68	12.12	13.73	4.5	2.8	7.3
18F		6			2.83	7.47	9.55	12.19	14.0	2.8	18.2
19F					7.22	11.32	12.04	15.68	14.0	2.8	18.2
20F			6		8.19	12.23	12.97	16.54	14.0	2.8	18.2
21F					9.10	13.06	13.84	17.35	14.0	2.8	18.2
22F				5	9.97	13.87	14.68	2.10	14.0	2.8	7.3
23F	6			6	7.60	11.45	12.64	16.02	14.0	2.8	18.2
24F		5			11.56	1.03	16.21	3.55	4.5	2.8	7.3
25F		6			9.90	14.06	16.15	1.39	4.5	4.2	-2.2
26F		6			10.90	15.05	15.26	2.74	4.5	4.2	-2.2
27F					12.22	0.59	16.49	4.15	-5.0	4.2	-2.2
28F		5		5	13.40	0.97	0.97	5.41	-5.0	-6.7	-2.2
29F			5		14.03	1.65	1.81	6.07	-5.0	-6.7	-2.2
30F					14.58	2.27	2.45	6.67	-5.0	-6.7	-2.2
31F		6	6		10.59	14.52	15.20	2.41	4.5	4.2	-2.2
32F		5	5		17.78	6.01	5.95	10.07	-5.0	-6.7	-2.2
	200	186	190	181					26.0	6.3	79.5

The "Labor Cost--Plus/Minus" column clarifies how Labor Cost can be increased or decreased by saving 1 work-day of the Cycle Term. If workdays for both molding workers and steel bar placers are reduced by one day, a maximum of 19 workdays can be saved while the labor cost increases by ¥8-million. 3rd, 5th, 11th, 12th, 13th, 14th, 15th, and 16th also, it is noted that the expected effect of overtime work varies by job-titles. For example, under the time goal of construction set at 185 days, overtime is scheduled for molding workers on the 3rd, 5th, 11th, 12th, 13th, 14th, 15th, and 16th floors, and for steel bar workers on the 4th, 6th, 7th, 28th, 29th, 30th and 32Nd floors (ref. Table 4), where total of 15 workdays can be saved and a minimum cost increase can be realized. Thus, the authors succeeded in developing a methodology by which an optimal combination of overtime for workers can be realized.

Fig. 7 graphically illustrates difference in Balance Loss of work-process between Pattern I and pattern IV. The higher the floor goes up, Balance Loss is seen also rising, but is seen reduced at each point of work-process improvement. So is workers' idle time, too. It also shows that maximum rate of Balance Loss for Pattern I was about 15% which is equivalent to some 8 hours work on the 7-day work-process. This situation was caused by the concrete-layers' 1-day assignment on the last day only of the Cycle Term, making them unable to reduce their idle time in excess of the 1/4-day allocation limit on the previous workday. It can be seen with Pattern IV that a 6-day Cycle Term was realized on the 10th floor and a 5-day Cycle Term on the 24th floor and above. It means a process improvement in overtime work reducing balance loss. However, on the 14th through 21sr floors, Cycle Terms could not be reduced making idle time increase, and so it was meaningless to let them work any unscheduled overtime. Thus, it can be said that Balance Loss data can serve as a valid index in examining the possibility to reduce Cycle Term.

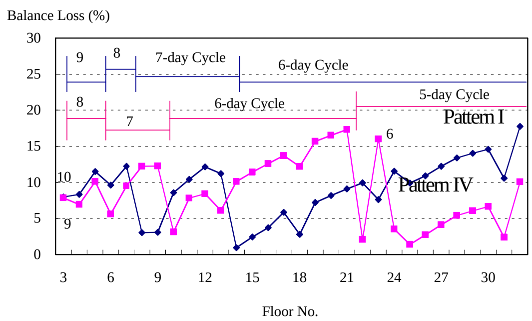

Fig. 7 Balance Loss Curves

Fig. 8 represents a total work-process plan developed by selecting an optimal pattern for each Cycle Term based on the Balance Loss and Smoothness index data for the four established Work Patterns. It resulted in a straight reduction in the Balance loss for all Cycle Terms at 10% or less. Specific figures for Smoothness Index (SI) came up as SI =2.12 on the 3rd floor, SI = 3.05 on the 32nd floor, and up to a maximum value of SI = 4.54 for all floors. Table 5 compares the Standard Work-process and an Optimal Work-process in terms of Cycle Term, Total Man-days, Total Man-hours worked and Total Cost resulting from the simulation. It clarifies that, within the same total working time, shorter Optimal Cycle Term, workers' Total Man-days and reduced Total Labor cost. Our simulation test, as described above, searching for optimal work-patterns and their appropriate combination, verified that project's work speed were stepped up and stabilized, and both labor and materials as supplied proved effectively utilized.

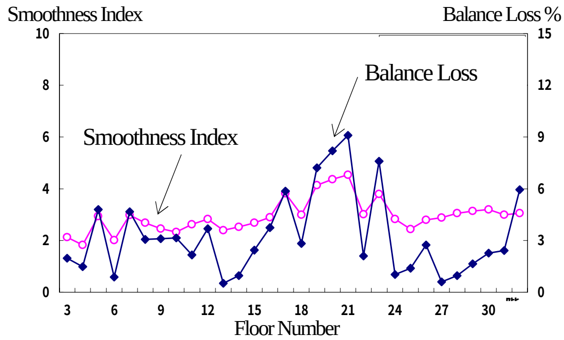

Fig. 8 Balance Loss and Smoothness Index Curves

Table 5 Comparison of Standard Work-process and Optimum Work-process

	Total Term (days)	Total Attendance (man-days)	Total Working Hours	Total Labor Cost (Unit: \10,000)
Standard Work Process (Regular Schedule)	200	5,200	43,426.9	9,838.1
Optimum Work Process	181	5,020	43,426.9	9,690.0

4. CONCLUSION

In this study, a construction planning phase for high-rise RC housing was simulated by a computer-aided tool. By focusing the study on overtime work in examining the possibility of process adjustment, the simulation was made more realistic. It resulted in assuring the effect of reduced cycle terms for workers by intentionally and smoothly allocating overtime. It also made it possible for any ineffective overtime plans to be constrained. Besides, we could propose a methodology to single out optimal combination of work plans based on the labor cost data forecast.

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