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AN OBSERVATIONAL STUDY OF THE PRODUCTIVITY OF FORMWORK IN BUILDING CONSTRUCTION

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Formwork is one of the essential elements of construction work in traditional reinforced concrete building construction. In addition to being complicated work, formwork is labor intensive and requires numerous, highly-skilled formwork carpenters. Labor accounts to over 50% of the cost of formwork, a large percentage relative to other types of basic construction work. To increase formwork efficiency, it is necessary to improve work methods. While productivity of formwork has been the focus of previous studies, effective work data such as detailed work processes or man-hours were not sufficiently obtained. This paper reports on an observational study carried out on fifteen building construction projects using work-study techniques, specifically work processes, man-hours, and number of workers in each work process. It highlights the process analyses of a typical formwork construction project and discusses the results of a statistical analysis of labor productivity related to all construction projects.

Keywords: Reinforced concrete construction, Productivity, Work study, Work process, Process analysis, Man-hours, Unit requirement.

1 INTRODUCTION

Formwork is an essential element of construction work in reinforced concrete building construction. In addition to being complicated work, formwork is labor-intensive and requires numerous, highly-skilled tradesmen such as formwork carpenters. To improve formwork efficiency, it is necessary to reduce labor by improving work methods, and to aim for higher labor efficiency using scientific management. This requires analyzing fundamental data such as work processes and work hours, and resolving work-related problems that focus on essential points of management.

2 OBJECTIVE AND SCOPE

Productivity of formwork has been the focus of previous studies. However, effective work data such as detailed work processes or man-hours were not sufficiently obtained to be useful in improving formwork activities. An observational study was undertaken and involved fifteen building construction projects. Work-study techniques were deployed. In this paper, the results of work process analysis and work productivity are discussed.

3 PREVIOUS STUDIES

Thomas and Zavrski (1999), in an attempt to establish a theoretical basis for productivity measurement, conducted studies of construction works that included formwork. Work efficiency varies depending on the work process, but since work methods are diverse and numerous, the details of a work process change considerably according to the work method. As a result, it is difficult to clarify problems in work using only the results of a time study targeting one or two work methods. Portas (2005), Elazouni (2011), and other researchers tried to introduce Neural Networks to predict productivity. However, since the primary focus of their studies was collecting basic management data, they did not touch upon the problems of work.

4 PLANNING OF THE SITE WORK STUDY

4.1 Target of the Study

Fifteen projects were involved in the study. The projects comprised 9 office buildings, 1 factory, 1 hospital, 1 school, 2 warehouses and 1 dormitory building. The buildings were constructed with widely-used general formwork methods such as plywood and precast concrete (PC) slabs. Structures were of reinforced concrete (RC) and steel reinforced concrete (SRC). The size of a warehouse was the largest compared to other projects. All others were mid-sized projects; 3 to 10 floors above ground, building areas of 364m^2 to 1,209m^2, total floor areas of 1,963m^2 to 7,320m^2, and building heights of 13.00m to 32.32m and the construction periods of 8 to 18 months.

Regarding the selection of construction projects, we concentrated on those using slab and wall formwork and conventional work methods, and tried to analyze the effects work methods exerted on each work. For slab formwork, we selected two methods: a conventional method combining 12 mm thick plywood slabs with steel props, and a steel lattice girder reinforced precast concrete method (hereafter referred to as the "L method"). For wall formwork, we selected three methods: a conventional method combining 12 mm thick plywood slabs with Ø48 mm steel pipe studs and wales, an improved external wall panel method, and a tile pre-placing form method.

4.2 Study Items

This paper aims to understand fundamental work data from the point of view of work processes and labor productivity in terms of man-hours and man-hours per unit quantity of work. For this purpose, the following items were studied.

(1) Project characteristics

(2) Work processes in formwork

(3) Man-hours in each work processes

4.3 Project Characteristics

There are numerous factors that may affect formwork productivity. For the purpose of the study, we focused on three factors: (i) work quantity, (ii) construction speed, and (iii) ability of workers. Derived from these factors are project characteristics such as:

- Work quantity – specifically constructed floor area; story height; and formwork quantity.
- Construction speed – specifically cycle time (number of days per story), and
- Ability of workers – specifically average age and average experience of workers.

4.4 Analysis of Work Processes in Formwork

Work processes were analyzed using the graphical symbols as defined by JIS (Japanese Industrial Standard) (JIS-Z 8206) 1982. To facilitate the analysis of work processes related to formwork, interviews were conducted with the relevant person in charge of scheduling for each project.

4.5 Measuring Man-Hours

To measure the man-hours using only a few observers, a time study was conducted by the equal interval work sampling method. The observational interval was 5 minutes. In previous studies, it was confirmed that workers learned very effectively until about the 3rd or 4th work repetition, stabilizing thereafter (Thomas *et al.* 1986) (Farghal and Everett 1997). Based on the results, we measured site work after the third work repetition carried out between the 3rd and 6th stories. The unit requirement M for each process is determined by Eq. (1).

$$M = \Sigma\ (w_i \cdot X \cdot\ t_i) \ /\ Q \tag{1}$$

where:

M : unit requirement (man-minute/m^2)
w_i : number of workers (number of workers)
t_i : working hours (min)
i : occurrence order
Q : work quantity (formwork quantity: m^2)

5 RESULTS OF THE STUDY

5.1 Project Characteristics

Table 1 shows the project characteristics. Project K was a large-scale warehouse with a floor area of 1,700m^2/story. The floor areas of remaining construction projects ranged from 332m^2 – 886m^2/story, with 603m^2/story being the average for the 15 projects. Story heights ranged from 2.85m - 5.00m; the formwork quantity ranged from 904m^2 - 3,824 m^2/story. The cycle time per story is 8-17 days. The average experience period in formwork varied with the sites, within a range of 8.9 - 29.8 years.

5.2 Work Process in Formwork

Process analysis was carried out to identify the work process in formworks. An example is depicted in Figure 1, i.e., the conventional formwork work process in project G. As shown in the chart, there are four primary routes that are, from left to right, (i) sheathing, (ii) main process, (iii) shuttering, and (iv) cross tie in a conventional formwork erection work. The conventional formwork consist of 24 work processes, which includes 11 operations, 5 transportations, 5 storage/stocks, 2 quantity inspections and 2 quality inspections.

Table 1. The results of observation on project characteristics.

Project	Constructed floor area (m^2/story)	Story height (m)	Quantity of formwork (m^2/story)	Cycle time (days/story)	Average age of workers (years old)	Average experience of workers (years)	Observed story
A	672	3.50	1,904	10	42.0	17.5	4
B	386	3.50	1,053	11	37.4	16.8	4
C	534	3.37	1,644	13	43.6	22.3	5
D	399	3.45	1,386	12	38.8	19.3	4
E	364	3.20	910	8	36.2	17.3	5
F	412	3.65	1,355	11	41.9	21.8	4
G	727	2.85	1,716	15	44.9	21.6	3
H	378	3.15	883	14	41.7	20.6	4
I	361	3.30	1,128	8	27.9	8.9	6
J	886	3.90	2,715	12	38.3	14.4	4
K	1,700	5.00	3,845	17	40.7	19.4	5
L	665	3.47	1,905	8	41.2	17.3	4
M	586	3.15	2,604	10	36.8	15.2	4
N	332	3.25	1,158	10	49.7	19.8	5
O	650	3.60	2,134	13	40.5	21.7	4

5.3 Relationship between Project Characteristics and Man-Hours

We conducted a multiple regression analysis between the man-hours and project characteristics, with man-hours as the dependent variable and project characteristics as the independent variables. For the independent variables, we took into consideration the six project characteristics: (i) constructed floor area, (ii) story height, (iii) formwork quantity, (iv) cycle time, (v) average age of workers, and (vi) average experience of workers. Among the six project characteristics, we recognize that constructed floor area and story height are very strong predictors of man-hours. As an example, Figure 2 depicts the linear relationship between story height and man-hours, which has a strong correlation of 0.859.

5.4 Relationship between [Story Height × Floor Area] and Unit Requirement

Taking unit requirement as the dependent variable, a multiple regression analysis was performed on the relationship between the usual six independent variables and the additional three created variables such as (i) formwork quantity / constructed floor area, (ii) story height × constructed floor area, and (iii) formwork quantity / [story height × constructed floor area]. As an example, Figure 3 depicts the linear relationship between [story height × constructed floor area] and unit requirement. A strong correlation of 0.719 is evident. The unit requirement increases with increment in [story height × constructed floor area]. In other words, when there is an increment in work area and story height, this brings about a corresponding increment in workers' movement and transportation distance. Hence the consequential impact is a lowering of work efficiency.

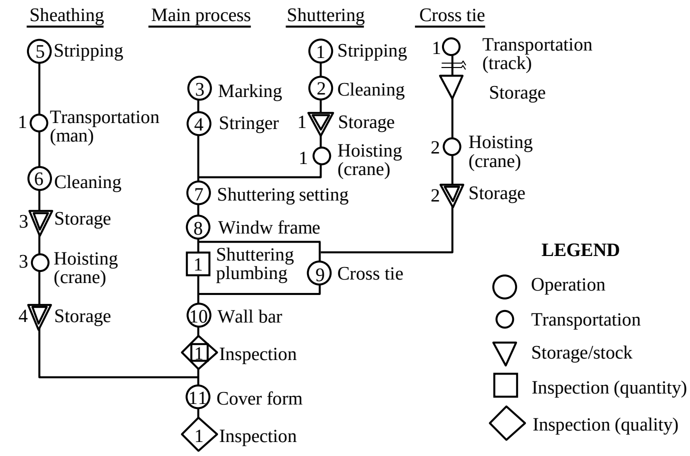

Figure 1. Work process in a conventional formwork erection (project G).

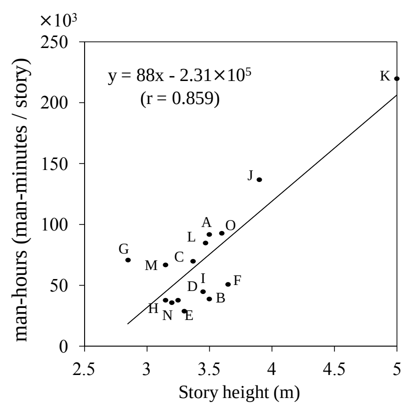

Figure 2. Relationship between constructed floor area and man-hours.

Considering the maximum, minimum, and mean values and from the viewpoint of building elements, the unit requirement for slab erection is comparatively small relative to other building elements. To verify the difference in the mean values of unit requirement among building elements, the analysis of variance was conducted. Table 2 shows the results. As shown in the Table, there is a significant difference between the unit requirements among building elements at 1% level of significance.

6 CONCLUSIONS

The paper demonstrated a methodology to predict man-hours and unit requirement related to formwork construction. Amongst the project characteristics that were investigated, it is discerned that story height, constructed floor area and [story height × constructed floor area] are excellent predictors of man-hours and unit requirement as dependent variables. Furthermore, analysis of variance indicted a significant difference in unit requirements between building elements such as column, beam, slab, etc.

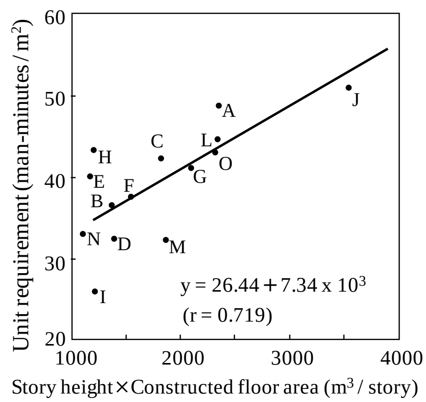

Figure 3. Relationship between [story height×constructed floor area] and unit requirement.

Table 2. Results of analysis of variance (mean value of unit requirement for each building element).

	Sum of sequences	Degree of freedom	Variance	Variance ratio 1)
Between subgroup	2,199	4	549.8	65.3**
Within subgroup	5,893	70	84.2	—
Total	8,092	74	—	—

Note 1) **: *Significance level 1% significant*

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