An observational study on the productivity of formwork in building construction

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ABSTRACT

Formwork is one of the essential elements of construction work in traditional reinforced concrete building construction. In addition to being complicated work, formwork is labour intensive and requires numerous, highly skilled workers such as formwork carpenters. In view of the fact that highly skilled formwork carpenters are in short supply and hence this spurs the search for construction techniques or methods that are less labour dependent. Formwork also exerts a direct influence on the surface quality and dimensional tolerance of concrete. Since the vast majority of buildings are constructed using concrete, the quality of the formwork will determine the level of workmanship of the construction work to follow. In order to increase formwork efficiency and the quality of construction work, it is necessary to improve work methods and work processes, and to aim for higher work efficiency using scientific management. This requires analysing fundamental data such as work processes and work hours, and identifying the problems that are inherent in the work itself and the essential aspects of management.

The observational study was conducted over fifteen projects to measure man-hours of formwork. Based on the data statistical analysis was carried out.

Keywords -
construction work; formwork; work study; process analysis; man-hours; productivity

1 Introduction

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. By observing the project characteristics of formwork, the study attempts to improve the construction quality and obtain relevant data in terms of the measures necessary to enhancing productivity

An observational study was undertaken and involved fifteen building construction projects. Work study techniques were deployed. In this paper, the results of a statistical analysis of the relationship between project characteristics and formwork productivity projects were discussed. The following items formed the core aspects for the study:-

(1) Analysis of work processes in formwork; and
(2) Statistical analysis of man-hours and unit requirement.

2 Previous studies

Research aimed at the efficiency of formwork began decisively in the 1960s. In attempts to better our understanding of construction productivity, Narita investigated formwork erection with specific focus on time measurement[2]. Thomas and Zavrski endeavoured to establish a theoretical basis for productivity measurement which included formwork[3]. Work efficiency varies with the work processes. Since work methods are diverse and particularly related to formwork, the details of a work process vary considerably in relation to the work method. As a result, it is difficult to identify problems in the work using only the results of a time study targeting one or two work methods. Portas[4], Sonmez[5], Elazouni[6], and others tried to introduce Neural Networks to predict productivity[7][8]. However the foregoing research attempts excluded project characteristics as determinants of formwork productivity. The latter shall be the focus for the study.

3 Objective and scope

In an attempt to shed light on our understanding of formwork productivity, relevant project characteristics are taken into due consideration. They are deemed as independent variables and therefore determinants of formwork productivity on a project site.

4 Planning of the site work study

4.1 Target of the study

Table 1. briefly outlines the 15 projects involved in the study. The projects comprise 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 project K (warehouse) was the largest compared to other projects. All others were mid-sized projects; 3 to 10 floors above ground, building areas of 364 to 1,209m^2, total floor areas of 1,963 to 7,320m^2, and building heights of 13.00 to 32.32 m and the construction periods of 8 to 18 months.

Table 2 outlines the formwork methods for slabs and walls for each project. For slab formwork, we selected two methods: (i) a conventional formwork combining 12 mm thick plywood slabs with steel props; and (ii) a steel truss reinforced method, (this method is hereafter referred to as the "L method" (Figure 1)). For wall formwork, we selected four methods: (i) a conventional combining 12 mm thick plywood; (ii) a panel method; (iii) a tile pre-placing form; and (iv) PC panel method.

Project	Slab	Wall
A	Conventional method 12mm plywood/Steel prop	Conventional method 12mm plywood
B	L method[1] (685mm truss pitch)	Tile pre-placing form (Tile sheet method)
C	Conventional method	Tile pre-placing form (Individual tile method)
D	L method (585mm truss pitch)	Giant shuttering form (H3.45m×W3.00m)
E	L method (585mm truss pitch)	PC[2] panel form (t =80mm)
F	L method (620mm truss pitch)	PC panel form (t=80mm)
G	Conventional method 12mm plywood/Steel prop	Conventional method 12mm plywood
H	Conventional method 12mm plywood/Steel prop	PC panel form (t =75mm)
I	Conventional method 12mm plywood/Steel prop	Tile pre-placing form (Tile sheet method)
J	Conventional method t=30mm cemented excelsior board/Steel prop	Giant shuttering form (H 3.90m×W3.25m)
K	Flat slab L method	Giant shuttering form (H5.00m×W6.25m)
L	L method (660 truss pitch)	PC panel form (t =75mm)
M	Conventional method 12mm plywood/Steel prop	Giant shuttering form (H3.15m×W3.00m)
N	Conventional method 12mm plywood/Steel prop	Giant shuttering form (H3.15m×W3.00m)
O	Conventional method 12mm plywood/Steel prop	Tile pre-placing form (Tile sheet method)

Note: 1) L method: Cast in lattice girders PC slab
2) PC: Precast concrete

Table 2. Outline of formwork methods

Table 1 Outline of the projects involved in the study

Project	Function of building	Structure	Building size: Storey	Building area (m^2)	Total floor area (m^2)	Building height (m)	Construction period (month)
A	Factory	RC[1]	4	1,088	3,234	20.50	8
B	Office	SRC[1]	8	398	2,864	28.70	12
C	Office/shop	SRC	8	630	4,066	25.95	15
D	Office	SRC	8	428	3,332	27.90	12
E	Office	SRC	9, B1[2]	364	3,034	30.35	15
F	Office	SRC	8, B1	412	3,468	30.40	13
G	Hospital	RC	3	797	2,252	13.00	12
H	School	RC	6, B2	378	1,963	19.07	13
I	Office	SRC	10, B1	372	3,830	31.00	16
J	Office	SRC	5	1,209	4,900	23.45	14
K	Warehouse	RC	5, B1	7,609	35,943	26.80	18
L	Office	SRC	8, B2	778	7,320	32.32	15
M	Warehouse	SRC	8, B1	743	4,514	25.00	11
N	Dormitory	RC	7	454	2,342	23.80	1
O	Office	SRC	7, B1	752	4,493	26.30	12

Note: 1) RC: Reinforced concrete, SRC: Steel reinforced concrete
2) B: Basement floor

Figure 1. L method (Cast in lattice girders PC slab)[9]

Figure 2. Conventional column and beam formwork[10]

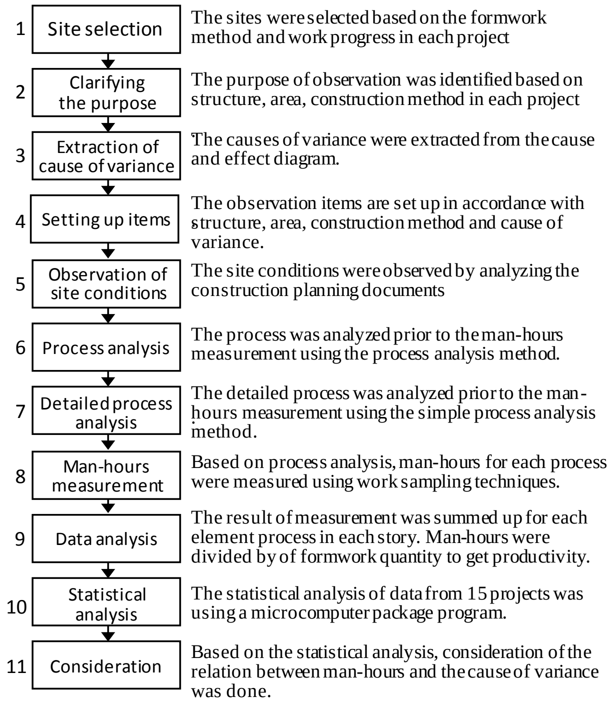

Figure 3. The study procedure

A typical conventional formwork is shown in Figure 2.

4.2 Study items

The paper aims to observe fundamental work data from the view point of work processes and labour productivity in terms of man-hours. The following items are of concern here:

(1) Project characteristics
(2) Work processes in formwork
(3) Man-hours

4.3 Study procedure

Figure 3 shows the study procedure for each project. First, select the projects, construction conditions and the purpose of the study were considered (Steps 1 and 2). Next, the causes of variance were extracted based on the project conditions, and set up observation items (Steps 3 and 4). Project conditions were observed (Step 5). Work processes were analysed based on a typical storey's schedule (Step 6), and based on these, the detailed processes were analysed using process analysis (Step 7). In Step 9, based on the detailed process analysis, man-hour for each process is measured using work sampling method. Man-hour data was calculated (Step 9) and statistically analysed (Steps 10 and 11).

The observations were conducted over a significant period of time and with each project study period averaging about two weeks.

4.4 Project characteristics

There are numerous factors which 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 three factors are project characteristics such as:

Work quantity – specifically constructed floor area; storey height; and formwork quantity.

Construction speed – specifically cycle time (number of days per storey)

Ability of workers – specifically average age and average experience of workers

4.5 Analysis of work processes in formwork

To facilitate the analysis of work processes related to formwork, interviews were conducted with the relevant person - in - charge of scheduling for each project. The analysis involved man-hours related to each storey.

4.6 Measuring man-hours

Man-hours were measured using a spot observation method. The observation interval was 5-minutes which was determined based on the observers' physical limit and data accuracy level. Two observers made the site rounds observation of 2 to 40 workers. Observations were carried out continuously from the start to the end of work, excluding lunch time.

In previous studies, it was confirmed that workers learned very effectively up to about the 3rd or 4th storey of repetition and stabilizing thereafter[12][13][14]. Therefore, in order to obtain data at the point at which work had stabilized, we measured after repeat three stories between the 3rd and 6th stories.

To obtain the man-hours (unit: man-minute), we totalled the man-hours for each process. The unit requirement for each process M of formwork was calculated using Equation (1).

$$M = \sum(w_i \cdot X \cdot t_i) / Q \quad (1)$$

where:

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

5 Results of the study

5.1 Generally about the project characteristics

Table 3 shows the project characteristics. Project K was a large-scale warehouse with a floor area of 1,700 m^2 /storey. The floor areas of remaining construction projects ranged from 332 – 886m^2/storey, with 603m^2/storey being the average floor area for the 15 projects. Storey heights ranged from 2.85 - 5.00m. The formwork quantity ranged from 904 - 3,824 m^2/storey. The cycle time per storey is 8-17 days per storey; with projects E and L requiring the shortest time at 8 days and project K the longest at 17 days. The average age of workers varied with the sites; with a range of 27.9 - 47.9 years old and a spread of 20 years. The average experience period in formwork also varied with the sites; within a range of 8.9 - 29.8 years and a spread of 20.9 years.

5.2 Analysis of man-hours

5.2.1 Relationship between project characteristics and man-hours

Table 4 shows the results of determining the man-hours for each building element in the erection process. Inspection, concreting, observation, and removal of formwork were excluded from the data. Total man-hours for each project are given in the extreme right column which ranged between 29,330 and 220,240 man-minutes/storey.

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. Table 5 shows the results.

For the independent variables, we took into consideration the six project characteristics: (i) constructed floor area, (ii) storey height, (iii) formwork quantity, (iv) cycle time, (v) average age of workers, and (vi) average experience of workers.

The multiple correlation coefficient is 0.922. It can be inferred here that the six project characteristics collectively are good predictors of the dependent variable i.e. man-hours. Looking at the independent variables individually, the partial correlation coefficients between the independent variables of

Table 3. The results of observation on project characteristics

Project	Constructed floor area (m^2/storey)	Storey height (m)	Quantity of formwork (m^2/storey)	Cycle time (days/storey)	Average age of workers (years old)	Average experience of workers (years)	Observed storey
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	29.8	5
O	650	3.60	2,134	13	40.5	21.7	4

Table 4. Man-hour for each building element in erection process (unit: man-minutes/storey)

Project	Marking	Pre-fab.	Hoisting	Trans-portation	Erection					Allo-wance	TOTAL
					Column	Beam	Slab	Wall	Staircase		
A	—	12,200	8,255	1,975	1,015	9,665	10,699	23,680	7,015	18,420	92,424
B	—	245	2,275	1,585	1,760	3,475	4,515	13,810	2,070	9,045	38,830
C	2,145	—	3,705	2,465	2,870	5,415	5,120	26,625	4,360	16,980	69,685
D	1,110	3,375	1,950	2,560	2,785	3,980	4,860	13,335	2,785	8,545	45,280
E	1,500	1,570	3,000	1,270	2,155	3,870	2,860	9,805	1,590	8,685	36,365
F	1,550	1,150	7,365	495	2,430	4,475	6,315	16,655	2,985	7,820	51,240
G	3,010	7,140	6,580	2,960	2,490	6,875	8,115	13,595	3,720	16,155	70,600
H	520	1,085	860	2,015	1,245	2,690	1,960	18,455	3,520	6,085	38,444
I	1,110	—	2,930	870	1,225	2,805	2,165	8,735	1,480	7,960	29,330
J	2,240	7,020	9,990	8,145	4,875	13,405	9,135	40,330	10,385	31,425	136,950
K	1,110	5,120	27,880	13,135	10,140	7,600	43,890	52,705	8,835	49,825	220,240
L	780	4,345	8,530	3,790	3,190	7,485	8,510	31,765	3,045	13,780	85,310
M	1,115	7,550	4,980	945	1,565	9,035	4,595	20,525	2,990	13,555	66,855
N	1,460	2,175	4,010	1,275	2,265	2,385	5,760	9,870	1,670	7,625	38,495
O	2,375	5,505	5,505	1,660	6,420	14,770	5,250	26,900	6,355	19,735	92,650

Table 5. Results of multiple regression analysis between project characteristics and total man-hours

	Item \ Independent Variable	Constr. floor area	Storey height	Formwork quantity	Cycle time	Average age of workers	Average experience of workers
Partial correlation coefficient	Constructed floor area	1.000	—	—	—	—	—
	Storey height	0.723	1.000	—	—	—	—
	Formwork quantity	0.914	0.736	1.000	—	—	—
	Cycle time	0.629	0.380	0.489	1.000	—	—
	Average age of workers	0.094	-0.038	0.041	0.414	1.000	—
	Average experience of workers	-0.059	-0.064	-0.123	0.411	0.918	1.000
	Total man-hours	0.978	0.855	0.932	0.569	0.122	-0.044
Regression coefficient		62	29,633	16	824	3,337	-3,038
Standard regression coefficient		0.433	0.290	0.253	0.045	0.323	-0.283

Notes: *Multiple correlation coefficient = 0.992*
Construction in the regression equation = -179795

constructed floor area, storey height and formwork quantity and the dependent variable of man-hours are considered very strong with the strength varying from 0.855 to 0.978. The partial correlation coefficient between the independent variable of cycle time and the dependent variable of man-hours is moderately strong at 0.569. The independent variable of average age of workers is found to be weakly correlated with the dependent variable of man-hours at 0.122. Lastly, the average experience of workers can be considered negligibly correlated with man-hours at -0.044.

Amongst the six project characteristics, it is recognised here that constructed floor area, storey height and formwork quantity are very strong predictors of man-hours. Figure 4 depicts the linear relationship between constructed floor area and man-hours which has the highest correlation of 0.978.

For a given constructed floor area, the derived straight line graph can be used as a basis to predict the man-hours per storey required. The storey height of project K is 5 m, a somewhat special case compared

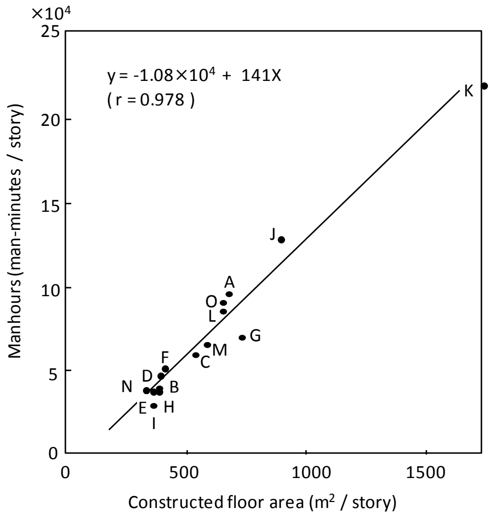

Figure 4. Relationship between constructed floor area and man-hours

with other projects. By excluding project K, Figure 5 shows the relationship between (storey height x constructed floor area) and man-hours. The correlation coefficient is 0.990; admittedly a high correlation. In other words, within a storey height range of 2.85 - 3.90 m, (storey height × constructed floor area) is a valid independent variable and a strong predictor of man-hours. Mindfully of the high correlation between formwork quantity and man-hour (at 0.932), it is considered appropriate to express work efficiency in formwork in terms of unit requirement.

5.2.2 Relationship between work quantity and man-hours

Table 6 shows the results of the regression analysis of the relationship between formwork quantity and unit requirement.

Table 6. Results of regression analysis between work quantity and man-hour

Process		Correlation coefficient	Proportion	Variance ration[1)]
	Marking	0.096	0.009	0.10
	Pre-fabrication	0.444	0.197	2.70
	Hoisting	0.891	0.794	50.20**
	Transportation	0.866	0.750	39.00**
Erection	Column	0.948	0.899	116.08**
	Beam	0.908	0.824	60.68**
	Slab	0.957	0.916	143.06**
	Wall	0.927	0.859	79.04**
	Staircase	0.563	0.317	6.02*
	Allowance	0.960	0.921	152.54**

Notes 1) ***: Significance level 1% significant*
**: Significance level 5% significant*
2) *The quantity of work is floor area (m^2)*

Figure 5 is an example of the relationship between formwork quantity and man-hour in wall erection, the erection process with the highest man-hours. Excluding staircases, the correlation coefficient between volume of the work and man-hour in each building element is greater than 0.900; admittedly a high correlation. Possible reasons of a high correlation between formwork quantity and man-hour in staircase erection can be explained as bellow. Since the staircases have complicated form compare to other elements such as column, beam, slab, etc., the work is quite difficult. Therefore, work efficiency is determined not only by quantity but also by other factors such as complexity of the form and work processes. Except marking, pre-fabrication, the values of correlation coefficient are greater than 0.800. As mentioned above, at the detailed process level, a high correlation exists between formwork quantity and man-hour.

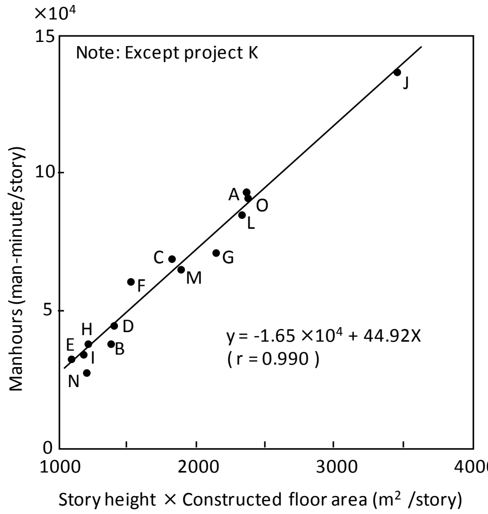

Figure 5. Relationship between (storey height × constructed floor area) and man-hours

5.3 Analysis of unit requirement

5.3.1 Calculation and statistical analysis of unit requirement

In addition, by multiplying the total man-hour per storey by the total formwork quantity, the overall unit requirement can be obtained. Based on these calculations statistical analysis was conducted.

Table 7. Statistical values of unit requirement for each process

Process \ Item		Sample size	Maximum	Minimum	Mean	Standard deviation	Coefficient of variation
	Marking	13	4.4	0.7	2.9	1.3	0.45
	Pre-fabrication	13	24.2	0.9	9.2	7.6	0.83
	Hoisting	15	6.7	1.0	3.7	1.9	0.52
	Transportation	15	3.4	13.8	1.5	0.9	0.57
Erection	Column	15	39.9	13.7	26.2	7.9	0.30
	Beam	15	42.2	8.1	23.8	7.1	0.30
	Slab	15	30.1	16.6	15.3	5.3	0.34
	Wall	15	46.0	15.9	30.2	8.0	0.26
	Staircase	15	58.6	15.9	29.3	13.8	0.47
	Allowance	15	30.2	5.8	10.1	5.9	0.59
	TOTAL	15	57.6	26.0	40.8	8.1	0.20

Notes: *The unit is man-minute/m^2 except "sample size" and "Coefficient of variance".*
The unmeasured items such as Marking and Pre-fabrication are eliminated.

Table 8. Results of multiple regression analysis between project characteristics and unit requirement

	Item \ Independent variables	constr. floor area	storey height	formwork quantity	cycle time	average age of workers	average experience	form quantity /constr. area	storey height × constr. area	formwork quantity / (storey h × constr. area)
Partial correlation	constructed floor area	1.000	—	—	—	—	—	—	—	—
	storey height	0.823	1.000	—	—	—	—	—	—	—
	formwork quantity	0.914	0.736	1.000	—	—	—	—	—	—
	cycle time	0.629	0.380	0.489	1.000	—	—	—	—	—
	average age of workers	0.094	-0.038	0.041	0.414	1.000	—	—	—	—
	average experience	-0.059	-0.064	-0.123	0.411	0.918	1.000	—	—	—
	formwork quantity/constructed area	-0.327	-0.233	0.057	-0.389	-0.097	-0.023	1.000	—	—
	storey height × constructed area	0.983	0.897	0.876	0.597	0.058	-0.047	-0.335	1.000	—
	formwork quantity/ (storey height × constr. area)	-0.548	-0.588	-0.203	-0.423	-0.057	0.014	0.913	-0.586	1.000
	unit requirement	0.779	0.648	0.640	0.545	0.330	0.115	-0.563	0.746	-0.724
	Regression coefficient	-0.128	-15.250	0.036	-0.086	0.961	-0.353	-7.185	0.012	-55.777
	Standard regression coefficient	-5.505	-0.922	3.596	-0.029	0.575	-0.204	-0.507	2.812	-1.416

Note: *multiple correlation coefficient = 0.988, constant in the regression equation = 120.683*

Table 7 shows the results of a statistical analysis of the unit requirement for each process. The coefficient of variation of unit requirement for the erection processes are relatively low, from 0.26 to 0.47, while others are from 0.45 to 0.83.

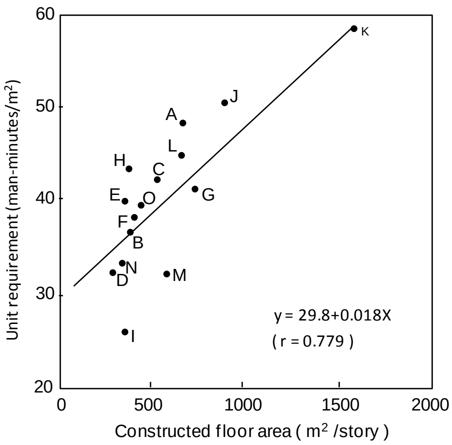

Figure 6. Relationship between constructed floor area and unit requirement

5.3.2 Relationship between project characteristics and unit requirement

Taking unit requirement as the dependent variable, multiple regression analysis was performed on the relationship between the usual six independent variables and the additional three variables such as (i) formwork quantity / constructed floor area, (ii) storey height×constructed floor area, and (iii) formwork quantity / (storey height×constructed floor area). The results of the analysis are shown in Table 8.

The multiple correlation coefficient is 0.988. This illustrates that collectively the independent variables are excellent predictors of the unit requirement as dependent variable. As for the partial correlation coefficients between unit requirement and the independent variables, notably: (1) constructed floor area is correlated at 0.779; (2) (storey height×constructed floor area) is correlated at 0.746; and (3) (formwork quantity×constructed floor area) at -0.724. These correlations are the largest. The relationship between constructed floor area and unit requirement is shown in Figure 6. The unit requirement increases according to increase of constructed floor areas. As the work area increases, movement of workers and transportation distance increase which lower the work efficiency.

Figure 7 shows the relationship between (storey height × constructed floor area) and unit requirement. There is a positive (should be negative) correlation between these variables This also results from a larger work area, but also because the difficulty of work increases as storey height increases.

5.3.3 Unit requirement for each building element

Considering the maximum, minimum, and mean values shown in Table 7 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 9 shows the results. As shown in the Table 9, there is a significant difference between the unit requirement among building elements at 1% level of significance. Furthermore, to verify the difference in the mean values for unit requirement for other building elements except for slab, the analysis of variance was conducted. Table 10 shows the results. As shown in the Table, no significant difference was obtained at 1% level of significance.

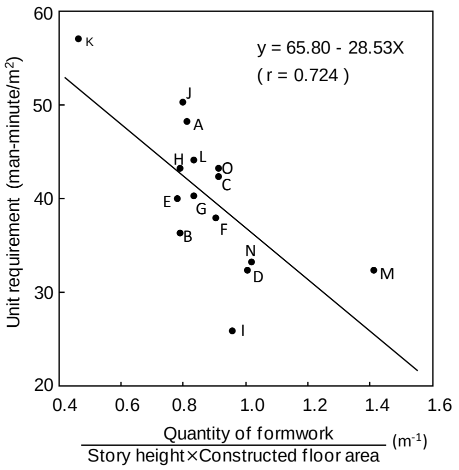

Figure 7 Relationship between formwork quantity/(storey height × constructed floor area) and unit requirement

Table 9. 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*

Table. 10. Analysis of variance results excluding slab (mean value of unit requirement for each element)

	Sum of sequences	Degree of freedom	Variance	Variance ratio
Between subgroup	398	3	132.5	1.36
Within subgroup	5,469	56	97.7	—
TOTAL	5,867	59	—	—

6 Conclusion

The paper has demonstrated a methodology to predict man-hours and unit requirement related to formwork construction on project sites. Selected project characteristics such as constructed floor area, storey height, formwork quantity, cycle time, average age of workers and experience of workers have been shown to have strong predictive power of man-hours as dependent variable. The foregoing six project characteristics together with additional three variables such formwork quantity / constructed floor area, (storey height×constructed floor area), and formwork quantity / (storey height×constructed floor area) are similarly excellent predictors of unit requirement as dependent variable.

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References

[1] Moselhi, O. and Khan, Z. Analysis of labour productivity of formwork operations in building construction, *Construction Innovation*, 10 (3): 286 – 303, 2010 construction, *Construction Innovation*, 10 (3): 286 – 303, 2010

[2] Narita, M. Measuring the time on formwork erection work in a building project, In *Proceedings of Architectural Institute of Japan Annual Meeting*, 301-302, Hokkaido, Japan, 1969

[3] Thomas, H. R. and Zavrski, I. Construction Baseline Productivity: Theory and Practice, *Journal of Construction Engineering and Management*, 125 (5): 295-303, 1999

[4] Portas, J. and Rizk, S. A. Neural Network Model for Estimating Construction Productivity. *Journal of Construction Engineering and Management*, 123 (4): 399-410, 1997

[5] Sonmez, R. and Rowings, J. E. Construction Labour Productivity Modeling with Neural Networks. *Journal of Construction Engineering and Management*, 124(6): 498–504, 1998

[6] Elazounil, A. M., Ali, A. E. and , Abdel-Razek, R. H. Estimating the Acceptability of New Formwork Systems Using Neural Networks. *Journal of Construction Engineering and Management*, 131(1): 33–41, 2005

[7] Song, L. and AbouRizk, S. M. Measuring and Modeling Labour Productivity Using Historical Data. *Journal of Construction Engineering and Management*, 134 (10): 786-794, 2008

[8] Dikmena, S. U. and Sonmezb, M. An Artificial Neural Networks Model for the Estimation of Formwork. *Journal of Civil Engineering and Management*, 17 (3): 340-347, 2011

[9] EBAWE home page. Lattice girder floor. On-line: http://www.ebawe.de/en/anwendungen/elementdecke/index.php?pageid=, Accessed: 17/12/ 2014.

[10] Okamoto construction Co. Ltd. On-line. Formwork construction. On-line:http://www.okamoto-co.jp/construction/FormWork-construction.html, Accessed: 10/11/2014.

[11] Thomas H. R., Mathews C. T. and Ward J. G. Learning Curve Models of Construction Productivity. *Journal of Construction Engineering and Management*, 112 (2): 245–258, 1986