pISSN 1598-2033
eISSN 2233-5706
J. Korea Inst. Build. Const., Vol. 15, No. 6
http://dx.doi.org/10.5345/JKIBC.2015.15.6.653
www.jkibc.org

Evaluation of Construction RCB Exterior Wall Formwork according to Placing Height on Nuclear Power Plant

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Abstract

Technologies for reducing construction duration are key factors in nuclear power plant construction projects, as a reduction in construction duration at the construction phase leads to a reduction in construction cost and an increase in profits through the early operation of the nuclear power plant. To analyze the constructability of the height of single-layer placement of formwork for the Reactor Containment Building (RCB) exterior wall through lateral pressure according to the height of concrete placement, the deformation criteria for formwork, and a new form design, 'MIDAS GEN (hereinafter referred to as MIDAS)' is used in this study. The cost and workload of formwork are derived according to the unit of height of the RCB exterior wall. Based on the result, it was found that the higher the RCB exterior wall, the higher the material cost, and the less the construction duration and the less the total number of formwork layers. Based on this result, it is believed that the material cost and the construction duration can be appropriately determined according to the formwork height.

Keywords : high-rise building, concrete work, formwork, reactor containment building(RCB)

1. Introduction

Korea has few natural resources, and its energy consumption is increasing annually. As such, energy shortages have become a pressing problem, and to address this problem Korea needs to build more nuclear power plants[1]. As the global nuclear energy market has been growing, the nuclear power plant construction has emerged as a keen interest for one of the driving forces of national growth, and it is thus critical to have competitiveness in the area of nuclear power technology in order to export nuclear power plants. While the Fukushima Daiichi nuclear disaster in 2011 led to changes in nuclear power and energy policy in some countries, many nuclear power plants are being built in India and Russia, leading to an increased dependency on nuclear energy in 2035[2].

Although they pose many problems, nuclear power plants have been continuously built in Korea and other countries due to the depletion in natural resources and the economic downturn. Significantly, Korea won a bid for a nuclear power plant construction in the United Arab Emirates, with a budget equivalent to USD 40 billion (approximately KRW 4.7 trillion), and it is expected that this will serve to enhance Korea's competitiveness in overseas nuclear power plant construction.

In particular, more thorough cost management is required in special purpose plant construction, including nuclear power plants, due to the gargantuan amount

Received : October 8, 2015
Revision received : October 23, 2015
Accepted : November 2, 2015
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of money invested in such projects[3]. One of the most important processes in an actual construction project is formwork, which has a significant impact on the overall economy and quality of the construction project and a great influence on construction duration, economy and improving constructability; for these reasons, meticulous care should be taken in formwork[4].

However, reducing the construction duration of a nuclear reactor building project can bring about a reduction in construction cost and profits through the early operation of the nuclear power plant, and thus the technology to reduce the construction duration can be one of key factors in a nuclear power plant construction project. A method to reduce the construction duration in a nuclear power plant construction is to develop a formwork with which single-layer formwork can be maximized. The height of a single-layer formwork is 3m, and if the height is increased to 4m, the construction duration can be reduced by about 2 months. However, as there are multiple variables in an actual construction process, it is difficult to make a simple arithmetic estimate. Thus, this study aims to evaluate the influence on constructability of changing the height of a single-layer formwork used for a nuclear power plant RCB(hereinafter referred to as Reactor Containment Building) construction. It is expected that the findings of this study can be utilized as fundamental data to develop an RCB exterior wall formwork of a nuclear power plant and evaluate the applicability of formwork height, It will modify the formwork design to contribute to RCB the outer wall formwork construction through better quality design.

The scope of this research is limited to the development of an RCB exterior wall formwork of a nuclear power plant that could maximize the workability of a single-layer formwork.

As part of an R&D project, the constructability of single-layer formwork for an RCB exterior wall of a nuclear power plant was analyzed by single-layer height, and the constructability by a single-layer height of newly designed formwork in terms of formwork drawing, formwork material, workload and process table, and the data was also analyzed in consultation with an RCB construction expert.

2. Major previous studies

Table 1 indicates the current state of the studies related with formwork and nuclear power plant. According to the formwork related study[5,6,7,8,9], formwork has been actively studied in terms of economic evaluation by form remaining period, form resistance and applicability. However, scant research has been conducted on constructability according to formwork height.

In addition, it was found in nuclear power plant related studies that productivity of rebar concrete work type and influence factor, and earthquake resistance design have been analyzed, but inadequate research has been done on the constructability of RCB formwork of a nuclear power plant. Therefore, a concrete study is needed to analyze the appropriate form height for a nuclear power plant by evaluating constructability according to form height for an RCB exterior wall of a nuclear power plant.

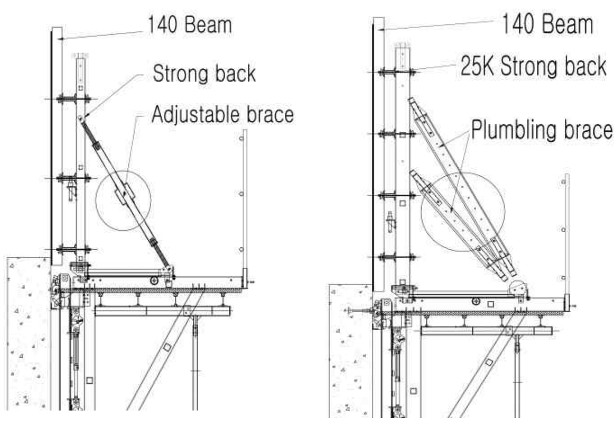
Table 1. Previous studies of formwork and nuclear power plant

Classification	Researcher	Title
Form work	Kim[3]	Structural bearing capacity ealuation of wall form system using fouble insulation material and metal web
	Kim[5]	An study on the economic evaluation of reinforced concrete structure according to reduction of form setting period
	Kim[1]	An assessment of field applicable of system form for reducing of the duration
Nunclear power plant	Huh[5]	Reinforced-concrete works productivity and influence factor analysis on nuclear-power-plant project
	Yi[3]	A seismic stability design by the KEPIC code of main pipe in reactor containment building of a nuclear power plant

3. Composition of the formwork system

3.1 Cross section of formwork by single-layer height

Figure 1 shows the drawings of 3m- and 4m-heighted formwork adjusted from a 3m-heighted formwork for an RCB exterior wall of a nuclear power plant. Unlike the existing 3m-high formwork, the 4m-high formwork has a longer strong back, and an adjusted brace was added to buttress the lateral pressure as the height is increased. In addition, the hydraulic system for the additional adjustable brace was improved accordingly. The strong back is a connector directly fixed on the formwork to the climbing system. The difference between adjustable brace and plumbing brace lies only in denomination, but they have the identical function used on the same position.

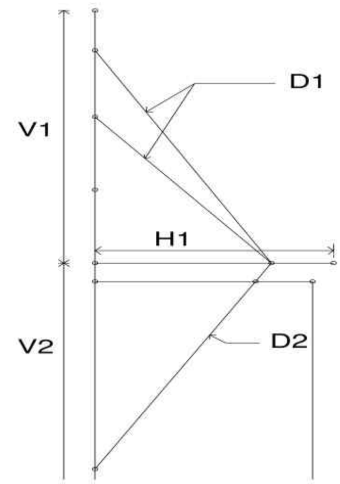


3m Type(A Type) 4m Type(B Type)

Figure 1. Cross-sectional view of formwork by height

3.2 Composition of formwork

As in Figure 2, basic components for the two formwork type and 3m-high formwork for an existing RCB exterior wall of a nuclear power plant is distinguished from a 4m-sized formwork newly made in this study. The difference between 3m- and 4m-high formwork is in the number of braces, as shown in Figure 1 in Section 3.1.



	3m Type(A Type)	4m Type(B Type)
V1	150x50x8x8	200x90x8x13.5(C=81)
H1	150x50x6x20	200x90x8x13.5(C=81)
D1	100x100x5.5x8	200x100x5.5x8
V2	200x70x7x10	200x90x8x13.5(C=81)
D2	200x70x7x10	200x90x8x13.5(C=80)

Figure 2. Formwork composition

4. Displacement analysis of RCB exterior wall formwork of a nuclear power plant

4.1 Lateral pressure by concrete pumping speed and temperature

The manufacturing of a single-layer RCB formwork of a nuclear power plant is greatly affected by the concrete placement height and the outdoor temperature. Table 2 indicates the lateral pressure according to formwork height, which is calculated based on the concrete specification 2009[10], and Table 3 was also referenced. The concrete pumping speed was set at 0.5m/hr, and the outdoor temperature was divided into 5℃(cold weather), 20℃(mild weather), and 40℃ (hot weather). The lateral pressure of formwork was calculated using the equation in Table 3 by dividing the height into less than 4.2m and higher than 4.2m.

Table 2. Calculation of lateral pressure according to height

Temperature	Concrete pumping speed 0.5m/hr	
Formwork height	4.2m less than	4.2m more than
5℃(hot weather)	29.3kN/㎡	75.4kN/㎡
20℃(mild weather)	21.1kN/㎡	49.1kN/㎡
40℃(cold weather)	16.8kN/㎡	35.1kN/㎡

Table 3. Concrete lateral pressure formula

1) Formwork less than 4.2m in height and concrete pumping speed of 2.1m/hr, least lateral pressure $P = C_\omega \cdot C_c [7.2 + \frac{790R}{T+18}]$ The minimum lateral pressure: 30.0kN/m^2	
2) Formwork higher than 4.2m in height and concrete pumping speed of 2.1m/hr $P = C_\omega \cdot C_c [7.2 + \frac{1160+240R}{T+18}]$	
C_ω	Unit weight coefficient 1.0
C_c	Admixture coefficient 1.2
R	Concrete pumping speed 0.5m/hr
T	5℃(hot weather) / 20℃(mild weather) / 40℃(cold weather)

4.2 Displacement analysis according to concrete lateral pressure

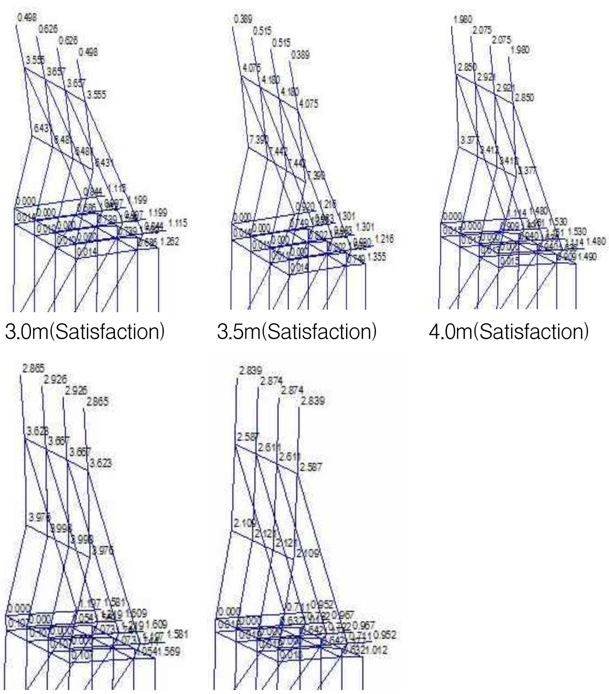
As the form height was increased, the lateral pressure changed. For this reason, the surface rating was set at A class in the deformation criteria for the mould plate specified in the provisional construction specification finally approved by the Ministry of Land, Infrastructure and Transport[11], and as in Table 4 the absolute deformation was set to be less than 3mm based on the deformation criteria for an RCB exterior wall formwork of a nuclear power plant.

Table 4. Deformation criteria of a mould plate

The rating of surface	Relative deformation	Absolute deformation
A degree	ln/360	3mm
B degree	ln/270	6mm
C degree	ln/180	13mm

4.3 Displacement of the RCB formwork of a nuclear power plant

To review the formwork structure for the RCB exterior wall of a nuclear power plant, 'MIDAS GEN (hereinafter MIDAS)' is used. The height was increased in increments of 0.5m in two cases: one from the existing formwork height of 3m up to 5m (3m, 3.5m, 4m, 4.5m and 5m) and the other from a newly developed height of 4m up to 5m (4m, 4.5m, and 5m). The displacement of the form was analyzed in the two cases after the components of a formwork were changed to satisfy the deformation criteria of a mould plate, and then the displacement was measured.

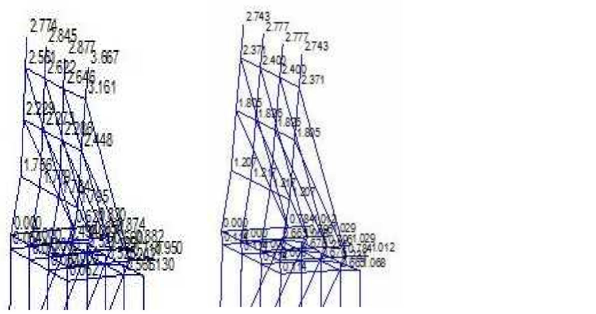


3.0m(Satisfaction) 3.5m(Satisfaction) 4.0m(Satisfaction)

4.5m(Satisfaction) 5.0m(Satisfaction)

Figure 3. MIDAS GEN analysis results of 3m(A Type) formwork

Figure 3. shows the results of an analysis of 3m-high single layer formwork and formworks by increasing 0.5m from 3m up to 5m using MIDAS. When the height was increased by 0.5m, the displacement caused by lateral pressure did not satisfy the deformation criteria, and the sizes of formwork components were also changed. In addition, by designing a new formwork system to be 4m high it was also analyzed by increasing its height by 0.5m up to 5m, and Figure 4 indicates the analysis results. As the height was increased, the displacement caused by lateral pressure did not meet the deformation criteria, and the composition of formwork was thus changed to meet the deformation criteria.



4.0m(Satisfaction) 4.5m(Satisfaction) 5.0m(Satisfaction)

Figure 4. MIDAS GEN analysis results of Table.8 4m(B Type) formwork

4.4 Components of formwork that satisfy the displacement requirements

Table 5 shows the components of the 3m-high formwork mentioned in Figure 3 in Section 4.3. There was no significant change found in 3m- and 3.5m high formwork. However, when the formwork was designed to be 4m high, the sizes of V1 and D1 increased twice, and it was found that the sizes of members need to be continuously increased due to changes in lateral pressure if the formwork is greater than 4.5m in height. Table 6 is the components of the 4m formwork stated in Figure 4 in Section 4.3. When the height was increased from 4m to 4.5m, there was a two-fold difference in lateral pressure. For this reason, the sizes of formwork components needed to be increased to buttress the increased lateral pressure. When comparing components between 3m-high and 4m-high formworks, it was found that the sizes of components should be changed significantly from 4m in the two formwork cases.

Table 5. Components of 3m(A Type) formwork

	3m	3.5m	4m
V1	150x50x8x8	150x50x8x8	250x50x15x8
H1	150x50x6x20	150x50x6x20	150x50x6x20
D1	100x100x5.5x8	100x100x5.5x8	350x200x25x11
V2	200x70x7x10	200x70x7x10	200x70x7x10
D2	200x70x7x10	200x70x7x10	200x70x7x10

	4.5m	5m
V1	350x100x15x8	400x200x20x20
H1	200x100x10x20	350x150x20x20
D1	500x300x60x60	500x300x60x60
V2	200x100x10x10	250x100x20x20
D2	450x200x20x20	450x200x20x20

Table 6. Components of 4m(B Type) formwork

	4m	4.5m	5m
V1	200x90x8x13.5(C=81)	350x150x8x50 (C=81)	350x150x8x50 (C=81)
H1	200x90x8x13.5 (C=81)	200x90x8x13.5 (C=81)	300x90x8x25 (C=81)
D1	200x100x5.5x8	450x200x50x50	500x200x50x50
V2	200x90x8x13.5 (C=81)	250x90x8x15(C=81)	400x100x8x40x (C=81)
D2	200x90x8x13.5 (C=80)	450x90x20x80 (C=80)	500x120x40x100 (C=80)

5. Constructability analysis of RCB exterior wall formwork

5.1 Cross sectional view of an RCB exterior wall of a nuclear power plant

An RCB exterior wall of a nuclear power plant consists of 18 layers of formwork, as shown in Figure 5. From the cross-sectional view of the exterior wall, there are equipment hatch and airlock that lead to the inside of the RCB wall so that except for the formwork for the typical floor, some part of the formwork should be carried out manually. Thus, a longer construction duration was required compared with the estimated construction duration based on the working days taken to finish the formwork for the typical floor. In other words, the average number of working days taken to finish a single-layer formwork is longer than the working days taken to finish the formwork for the typical floor

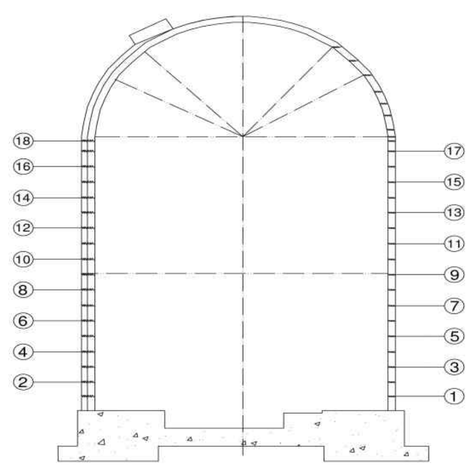


Figure 5. Cross-sectional view of RCB exterior wall

5.2 Formwork procedure and process

The construction sequence of the RCB exterior wall of a nuclear power plant is illustrated in Figure 6. The rebars are purchased, the purchased rebars and formwork are done, various items including formwork and sheath are inspected by a construction technician and QC inspector, and then concrete is placed if the inspection was passed. Table 7 indicates the entire process of RCB exterior wall formwork and concrete work based on the single layer formwork.

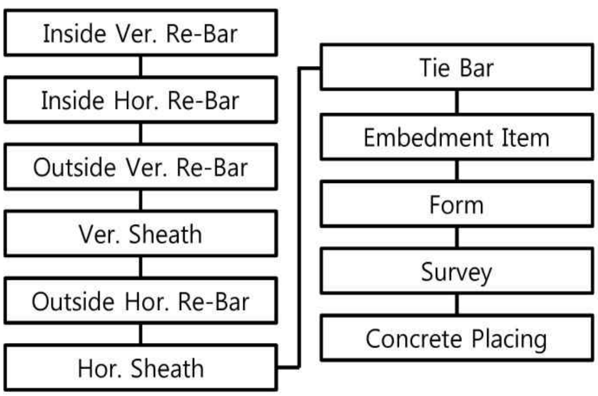


Figure 6. Formwork procedure

Table 7. Total number of working days by work type

Work	total	3m	3.5m	4m	4.5m	5m
Re-bar work	220	12.22	14.25	16.29	18.33	20.36
Formwork	55	3.06	3.57	4.08	4.59	5.1
Placing	18	1.00	1.19	1.36	1.53	1.7
Survey & Inspection	18	1.00	1.00	1.00	1.00	1.00
sum(day)	311	17.28	20.01	22.73	25.45	28.16

The average working days are calculated based on the single layer formwork and the height according to the materials. Figures 7 and 8 present the process table of formwork showing the typical floor of the RCB exterior formwork. The difference of process table between 3m and 4m formwork is increased work related with Inside Hor. Re-bar, Outside Hor. Re-bar, and Embedment Item, and the working days were increased due to horizontal rebars rather than vertical rebars.

5.3 Analysis of cost by formwork height and workload

The cost and workload calculated based on the 3m- and 4m-high single layer formwork are as shown in Table 8.

To support the increased lateral pressure caused by

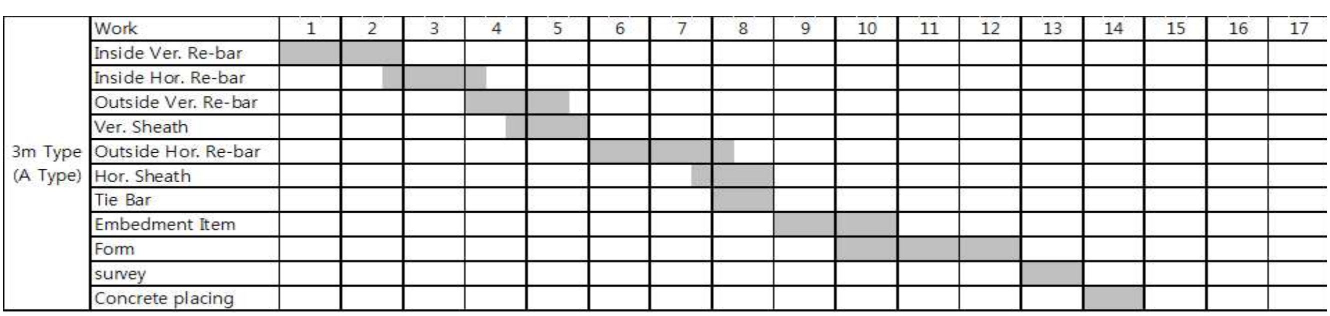


Figure 7. 3m (A Type) formwork procedure for the typical floor

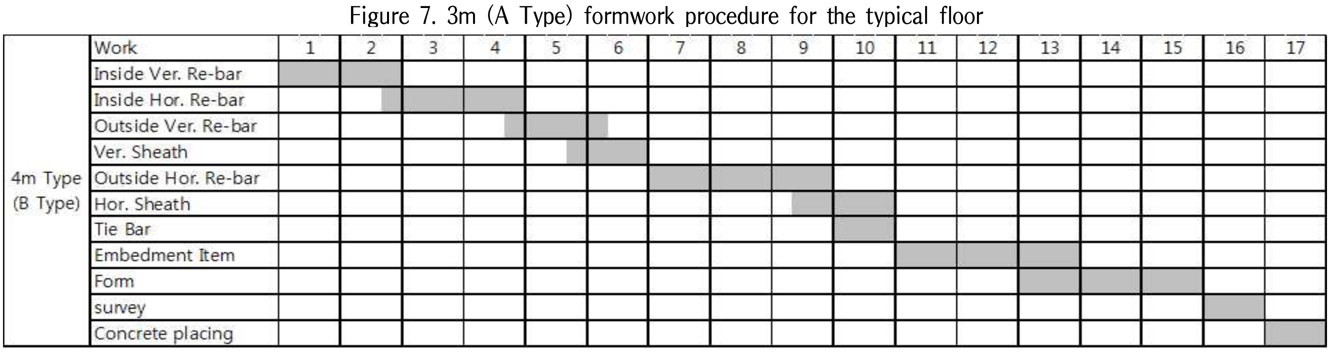


Figure 8. 4m (B Type) formwork procedure for the typical floor

Table 8. Cost and workload of 3m/4m formwork

Division	Formwork height	3m	3.5m	4m		4.5m		5m	
	Formwork type	A Type	A Type	A Type	B Type	A Type	B Type	A Type	B Type
Formwork cost (Unit:million won)	Hydraulic cylinder	156	156	156	312	156	312	156	312
	ACS frame	476	481	907	874	14,441	33,092	21,480	4,685
	Formwork materials	283	297	58	58	66	66	73	73
	Sum	632	637	1,063	1,186	14,441	33,471	21,480	47,165
Average workload of a single layer formwork	Construction duration of a single layer formwork(Day)	18	18	19		19		20	
	Rebar(Ton)	184	214	245		276		306	
	Formwork(m2)	466	543	621		699		776	
	Concrete(m3)	644	751	858		966		1073	
	Curing duration(Day)	7	7	7		7		7	
Entire construction	Entire construction duration(Day)	311	275	253		215		207	
	Total number of formwork layers(Day)	18	16	14		12		11	

increasing height by 0.5m in both of the two cases, the components were changed to satisfy the deformation criteria of the mould plate. In addition, the great difference between 3m- and 4m-high formworks lies in the additional cost of a hydraulic cylinder to endure more lateral pressure put on the 4m-high formwork. Changes in the component sizes brought about an increase in the production cost of formwork frame.

5.4 Analysis results

10 construction practitioners working at a nuclear power plant construction site were interviewed, and it was believed that there is no significant difference in the daily assigned workload even though there is difference in overall materials to be used. Figures 7 and 8 show that the number of working days is increasing due to the horizontal rebar work rather than the vertical rebar work.

Through Table 8, it was revealed that about 2 days would be taken whenever the height was increasing. However, the interview with construction practitioners refuted the calculated working days shown in Table 12. In other words, the horizontal rebar work would have no great impact on the construction duration. As the formwork is greater, the number of horizontal rebars also increases. However, when the formwork height is increased by 0.5m, one horizontal rebar is added in consideration of the rebar placement interval. The workload against the increased number of tons is believed to be not great. Moreover, even taking concrete placement into account, the workload is not increased significantly if the work is done earlier than usual or at night. Therefore, the construction duration for the RCB exterior wall did not differ greatly.

To be specific, there were increases of one day both in the case of a change from 3.5m to 4m and a change from 4.5m to 5m. Like workload of rebars and formwork, the workload of concrete also increases when the formwork is higher. The number of laborers required to install formwork was set at 110 people, but at this number the number of laborers to place concrete was excluded.

6. Conclusion

This study analyzes the constructability of RCB exterior wall formwork of a nuclear power plant with the increase in its height in order to provide fundamental data to bring the greater formwork in reality.

To estimate the displacement according to RCB exterior wall formwork of a nuclear power plant, the displacement was measured using MIDAS by increasing the height by 0.5m to be 5m. As the height increased, the formwork's deformation exceeded the deformation criteria. For this reason, to satisfy the deformation criteria of a mould plate, the sizes of formwork components were changed.

In addition, a new 4m-high formwork was designed, and its components were also changed as mentioned above. When the formwork height exceeded 4m, the components' sizes were changed greatly, and the formwork production cost was also significantly increased. Moreover, as the formwork was increased in height, the material cost and amount of rebars, formwork and concrete needed to produce a single layer formwork are also increased accordingly. However, if the formwork becomes greater, the workload is also increased, but the entire construction duration and the total formwork layers of the RCB exterior wall is decreased.

In this study, it was found that when formwork height exceeded 4m, the formwork components should also be increased. Considering this fact, it is believed that formwork height exceeding 4m for a single layer is not appropriate to reduce construction duration. Therefore, the increasing construction cost and the formwork height should be estimated appropriately. In this study, the constructability of RCB exterior wall formwork was analyzed according to height. However, the lack of detailed data and information on formwork is considered to be a limitation of this study. Thus, if the findings of this study are utilized as fundamental data in estimating the formwork height for the RCB exterior wall of a nuclear power plant, it will help to bring about a reduction in construction duration of a nuclear power plant and construction cost as a result.

Acknowledgement

"This work was supported by Kyonggi University's Graduate Research Assistantship 2014."

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