COMPARISON OF THE USE OF TRADITIONAL AND LOW WASTE FORMWORK SYSTEMS IN HONG KONG

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Keywords: Sustainable Development; Conventional Timber Formwork; Large Panel Steel Formwork; Pre-cast Concrete Semi-slab

Summary

Formwork is one of the most important temporary works for construction of reinforced concrete superstructure in building projects. The use of conventional timber formwork dominated the construction market in Hong Kong for many years. Nowadays, low waste construction technologies for superstructure construction are commonly adopted. The most commonly used low waste construction technology in Hong Kong is large panel steel formwork integrated with pre-cast concrete units. Compared with the use of conventional timber formwork system, the latter is considered a more sustainable construction method.

The selection of a formwork system and materials for the construction of superstructures would seriously influence the cost, time, and quality of project delivery. Other than these issues, environmental objectives and the associated waste generation during the course of construction are also of major concerns. Stakeholders of the construction industry in Hong Kong are consistently exploring the use of innovative construction technologies for various types of building projects in meeting both economic and environmental requirements.

This paper aims to compare merits and demerits of the use of a conventional timber formwork system and an integrated large panel steel formwork and pre-cast concrete semi-slab system in the construction of the superstructure of two identically designed school projects in Hong Kong. The comparisons include costs, time, quality and environmental issues of these two formwork systems. The study shows that despite the quality and environmental advantages of the new formwork system, the conventional timber formwork system is still more economically favorable in the projects studied. But if the recyclable metal formwork used in the new system could be used in other standard school projects after the completion of the project, economic advantage would be realized.

1. Introduction

The education reform proposal of Hong Kong was approved by the Government in 1999. The proposal recommended a holistic reform approach to improve the quality of education. One of its key emphases was to progressively replace all half-day primary school system by whole-day primary school system by 2007. In meeting this reform objective, the government of HKSAR must build more new primary schools to meet the demand of the new educational plan. Almost at the same time, the government of HKSAR promulgated its sustainable development policy. The concept of sustainable development is used as guiding principle for all government projects. The design and construction of new primary schools for education reform must therefore contain elements of sustainability. In this connection, a School Building Committee was established. The committee explored innovations of school building that provide both quality learning environment and flexibility in use of space. The Architectural Services Department (ASD) of HKSAR government undertook the task and supplied design solution.

1.1 Development Concept of New Primary School for the Education Reform

Elements of sustainable development are largely embraced in the new primary school design. Economic attribute focuses on value of land use and cost of construction. Social attribute concentrates on timely award contracts to stimulate the declining construction market, enhance workers safety in construction site, swiftly create adequate quality schools for the healthy development of school children. Environmental attribute emphasizes waste reduction, using renewable raw materials, recycle waste materials and energy saving during construction stage and when the schools are in use.

The design solutions consist of three different sizes of standard schools from 30-classroom, 24-classroom to 18-classroom respectively. The design of the school complex comprises two low rise buildings, the Classroom Block and the Assembly Hall/Special Room Block interconnected by a common area at each floor served as a lift lobby and a staircase lobby. The availability of three different designs was to provide flexibility to accommodate the land use economy and demand of the local community.

1.1.1 Sustainable objectives in the Design of New Primary School

With respect to the promotion of the concept of sustainable development, all the government development projects in Hong Kong are encouraged to follow most, if not all, sustainable construction criteria. These criteria encompassed design and operation issues and the design of the new schools needed to address the following requirements:

- Reduce energy consumption

To improve energy efficiency by reducing electricity demand through better overall thermal transfer value (OTTV) which is a measurement of the energy consumption of a building envelope. The OTTV value of ASD projects was set up at an average of $23W/m^2$. According to ASD's Environmental Report (2000), the new primary school design displayed an OTTV value of $11W/m^2$.

- Minimize Construction Waste

ASD encouraged reduction of construction waste by elimination of on site cutting, in-situ mixing of materials, and using prefabricated components.

- Reduce the use of depletable materials

Use of system formwork in association with pre-cast concrete units to substitute traditional timber formwork is highly recommended. Hui and Cheung (2000) suggested considerations are focused on various options in structural design such as standardizing the dimension of structural members for repetitive use of system formwork to avoid unnecessary cutting of depletable raw materials.

1.1.2 Selection of Construction Method

To attain the better environmental perfromance, Tang (2001) explained that it is important to adopt sustainable development approaches during the project inception stage and the initial design stage. The selection of construction methods are seriously influenced by the configuration of building and its structural members. BEER (2000) described that standardizing the dimension of structural members facilitates the use of reusable metal formworks pre-cast concrete elements which are believed to be able to generate less waste during construction.

2. Comparison of Outcomes with Different Construction Methods by Case Studies

The aim of this research is to explore whether adoption of low waste construction technologies to construct the superstructure of the new primary school is technically viable, financially beneficial, timely efficient and environmentally sustainable. To facilitate the study, two separate school projects were selected as case studies. Conventional timber formwork was used in the superstructure of the primary school in Lam Tin District; and large panel steel formwork in association with pre-cast semi-slab units were applied at another identically designed school project in Kowloon Bay. Both of the school projects were completed and put into use in 2003.

2.1 Case Study I - Conventional Timber Formwork System used in Lam Tin School

The Lam Tin School was a standard design 30-classroom primary school. The project was consisted of two reinforced concrete building complex, the Classroom Block and the Assembly Hall Block/special Room Block interconnected perpendicularly to each other by a common area. The contractor of this project used conventional timber formwork and cast in-situ concrete for the principal construct6ion method for the superstructure.

2.1.1 Conventional Timber Formwork System and Working Cycle

The timber formwork system for columns and walls used 18mm thick 6-ply Canadian Douglas Fir plywood as the vertical shutter formface. The shutters were vertically stiffened with 50mm x 75mm softwood sawn timber studs at an average of 180mm centre to centre. Concrete was placed between the shutters. The wall and column formwork was removed the next day after completion of concreting of the entire floor. The removed wall and column formwork was lifted to the upper floor level to repeat the working-cycle.

The beam and slab formwork system used 18mm thick 6-ply Canadian Douglas Fir plywood as beam & slab soffit. The soffits and side shutters were strengthened by timber runners of 50mm x 100mm softwood-sawn timber and propped by a propriety steel falsework system. According to the quantum of work of each floor, the planned working cycle of the superstructure of these two blocks was 11 days per floor.

All the soffits of slab, beam and cantilever structure had to be propped for at least 7 days, 16days and 28 days respectively according to the General Specifications (2002) to allow the concrete strength development. In order to achieve early removal of beam and slab formwork, individual dead propping supports were installed at suitable positions to sustain the dead and live load. Thus the beam and slab timber formwork system could be removed earlier and reused in upper floor to maintain its planned 11-day per floor working cycle.

In total, one set each of wall and column formwork, two sets of beam and slab formwork and 3 sets of cantilever beam and slab formwork were imperatively necessary. The breakdown of the 11-day per floor working cycle for the whole timber formwork system is as follow:

- Fix wall & column reinforcement and formwork 3 days
- Erect L/D scaffolding system and fix beam & slab formwork 3 days
- Place concrete to wall & column 1 day
- Fixing beam & slab reinforcement and E/M conduit 3 days
- Place beam & slab concrete 1 day **(Total: 11 days)**

2.1.2 Quantity of Timber Material used

The amount timber formwork used was measured. The plywood was measured in m^2, and the softwood sawn timber stiffeners was measured in metre run according to the Standard Method of Measurement (2001). As a common trade practice in Hong Kong, all soft wood sawn timber materials would be eventually converted to cubic metre (m^3). The amount of timber used for miscellaneous applications as side braces throughout the entire formwork system were soft wood sawn timber of various cross-sections were estimated by experience. The estimated quantity would be around 15% of the total timber studs and runners used in the relevant portion of works. The estimated quantity of side braces of the entire superstructure was later verified with material delivery record provided by the main contractor. The estimated figure was sufficiently close to the material delivery record.

The percentages of cutting wastage of the plywood and the soft wood sawn timber stiffeners for wall and column were estimated by experience (5% for plywood and 10% for softwood sawn timber stiffener). The cutting wastage for the beam and the slab system for plywood and soft wood sawn timber materials were estimated at 5% and 7% respectively.

The construction work for ground beam was carried out in sections according to the excavation progress. Whenever excavation work and concrete blinding layer for a particular section was ready, erection of formwork for the ground beam followed immediately. Therefore, cutting wastage was generally greater than the typical floors (about 20% for each concrete placing cycle). The site record reflected that 6-cycles had been done to complete all the ground beams.

To maintain the 11 days working cycle, the contractor worked out that one set of wall and column formwork for the entire floor area, two sets of beam and slab formwork, and three sets of formwork for the cantilever beam and slab portion were required. Table 1 shows the quantity of conventional timber formwork used in various portion of the entire superstructure.

Table 1 Calculation of Quantities of Conventional Timber Formwork for Various Elements of the Building

	Items	Area of Formwork for One Complete Floor (m^2)	Set(s) of Formwork Provided	Area of Formwork Provided (m^2)
1	Column	450	1	450
2	Wall	3,009	1	3,009
3	Miscellaneous walls for roof stair house, hose reel cabinets, dropper wall etc	140	1	140
4	Water tanks	123	1	123
5	Beam	502	2	1,004
6	Slab	1,168	2	2,336
7	Ground beam	185	0.5	92
8	Ground slab (suspension portion only)	42	Measured as required	42
9	Cantilever beam	129	3	387
10	Cantilever slab	154	3	462

The quantity of timber used for each portion of the entire conventional timber formwork system for Lam Tin School is measured and tabulated as follow:

Table 2 Summation of Items 1, 2, 3 and 4 of Wall and Column Portions

Wall and Column	Quantity (m^2)	Quantity (m)	Allow for Cutting Wastage	Total
18 mm thick plywood	3,722		3,722 x 0.05 = 186 m^2	3,908 m^2
50 x 75 mm softwood		21,700	21,700 x 0.1= 2,170 m	23,870 m
Miscellaneous softwood		21,700 x 0.15= 3,250	N/A	3,250 m

Table 3 Amount of Timber Formwork in Ground Beam and Ground Slab

Ground Beam and Ground Slab	Quantity (m^2)	Quantity (m)	Allow for Cutting Wastage	Total
18 mm thick plywood	190		190 x 0.2 x 6 cycles = 228 m^2	418 m^2
50 x 100 mm softwood		1,330	1,330 x 0.2 x 6 cycles= 1,596 m	2,926 m

Table 4 Amount of Timber Formwork for Superstructure Beam and Slab

Beam and Slab	Quantity (m^2)	Quantity (m)	Allow for Cutting Wastage	Total
18 mm thick plywood	3,340		3,340 x 0.07 = 234 m^2	3,574 m^2
50 x 100 mm softwood		30,100	30,100 x 0.05= 1,505 m	31,605 m
Miscellaneous softwood		30,100 x 0.15= 4,515	N/A	4,515 m

Table 5 Amount of Timber Formwork for Cantilever Beam and Slab

Beam and Slab	Quantity (m^2)	Quantity (m)	Allow for Cutting Wastage	Total
18 mm thick plywood	849		849 x 0.07 = 59 m^2	908 m^2
50 x 100 mm softwood		11,650	11,650 x 0.05= 582 m	12,232 m
Miscellaneous softwood		11,650 x 0.15= 1,747	N/A	1,747 m

The total quantity of timber materials used is summarized as follows:

- 18 mm thick plywood = (3,908 + 418 + 3,574 + 908) m^2 = **8,808 m^2**
- 50 x 100mm softwood sawn timber = 53,025 m run, i.e. 265 m^3
- 50 x 75mm softwood sawn timber = 27,120 m run, i.e. 102 m^3
- Total volume of softwood sawn timber (265 + 102) = **367 m^3**

2.1.3 Financial Cost

It is a common practice in the construction industry of Hong Kong to sublet all major trades to subcontractors. The formwork fixing trade for the superstructure of the Lam Tin School was subcontracted to a carpentry subcontracting firm as a supply and fix subcontract. The rates for each type of carpentry works were different in the bill of quantities. For simplicity, the following costs are categorized into three major groups – wall & column, beams, and slabs (including ground beams, beams and slabs of cantilever portion).

Table 6 Total Cost (Supply and Fix) of Conventional Timber Formwork for Lam Tin School

Category	Contract Arrangement	Material and Labour Cost
Column and Wall	Supply labour and material	HK$3,276,542
Beam	Supply labour and material	HK$1,060,731
Slab	Supply labour and material	HK$1,001,868
Total Variation Orders	All changes in column, beam and slab	(HK$70,521)
	Total Amount	**HK$5,268,620**

2.2 Case Study II - Large Panel Steel Formwork Integrated with Pre-cast Semi-Slab Unit used Kowloon Bay School

2.2.1 The Project Design and Contract Arrangement

The school project in Kowloon Bay was a part of the new educational concept called "school village". The school village was made up by three schools built on a common site sharing a larger open space and common facilities. The project comprised one 30-classroom secondary school, one 30-classroom primary school and one 24-classroom primary school located adjacent to each others. The design of two primary schools were similar to that used for the Lam Tin School and one contractor was responsible for constructing both schools.

2.2.2 Selection of Formwork System for the School Village Project

Since the schools were of identical design, the formwork system could be interchangeably used. The contractor chose the use of large panel steel formwork for wall and column and steel forms for beam. The slab construction was by pre-cast concrete semi-slab panels placed between the edge of beams. Figure 1 shows a typical floor layout framing plan of the 30-classroom primary school.

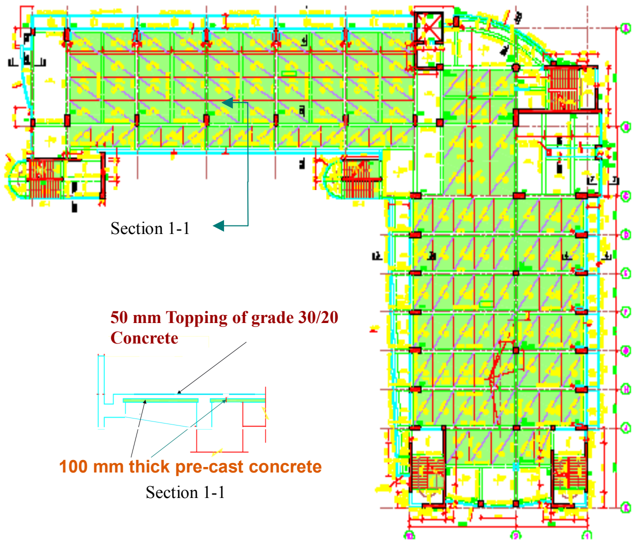

Figure 1: Typical Floor Layout and Semi Pre-cast Slab Arrangement

As shown in figure 1, (shaded colour portion) pre-cast concrete semi-slab panels were extensively used covering most of the floor area. The remaining areas such as all the staircases, A/C platforms, and lift lobby, where the beams were of longer span and for pre-cast concrete elements; slabs in these locations were cast in-situ with conventional formwork. Section 1-1 of Figure 1 illustrates the placement of pre-cast semi-slab units and the slab topping up concrete. The merit of choosing this formwork system was its interchangeable nature serving both the 3-classroom and 24-classroom schools. Due to the magnitude of the work and the time constrain, "one formwork two schools system" was adopted, i.e. one full set of large panel steel formwork for 30-classroom school would be provided for alternative uses between the 30-classroom and the 24-classroom school buildings.

2.2.3 Working Cycle

The site condition of the Kowloon Bay school project enabled a full range operation of tower cranes and crawler cranes so that lifting and shifting of the large panel steel formwork from one school building to another could be effectively carried out. The formwork erection was sequenced into four consecutive working portions operating in alternative manner between the two school buildings. Figure 2 shows the formwork zoning layout and working cycle schedule.

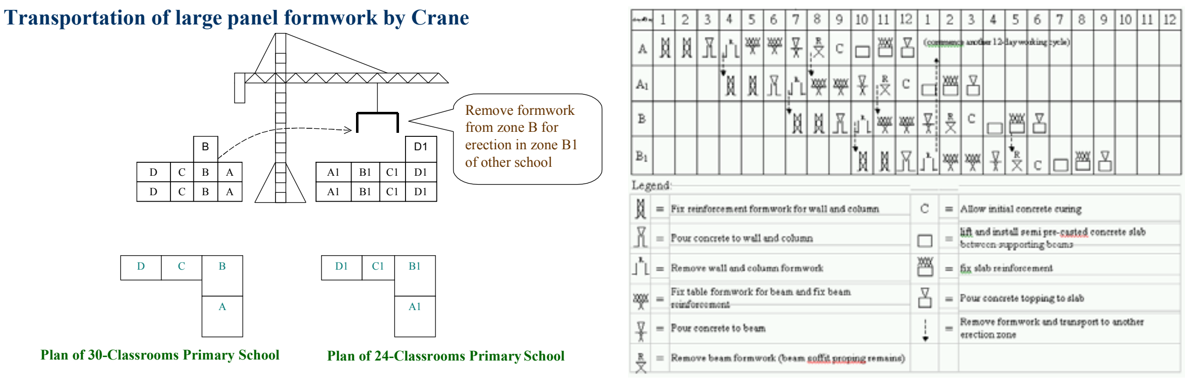

Figure 2: 12-Day Working Cycle for 2 Primary Schools with one Full Set System Formwork

The merit of using one full set of system formwork for two buildings was operationally simple. However, its demerit was self-restriction. The progress of one building would be delayed if there was delay in the progress of the other building. Because the formwork components are used interchangeably between the two buildings, the dismantling and lifting of the formwork component from one building to another had to maintain a "dismantle-remove-transport-receive & install" synchronized operation. For instance, after concrete was placed in the first portion of the column and wall of the 30-classroom primary school, the formwork had to be removed, lifted and momentarily transported by crane to the correspondent portion of the 24-classroom primary school for installation.

2.2.4 Quantity of Material Used

Material used in the large panel steel formwork system was mainly 4 mm thick mild steel sheet. The quantity of steel material and the associated cost was measured as follow:

Table 7 Quantity and Cost of Steel Formwork Material Used

Large Panel Steel Form Steel Material	Total Weight of HK$	Rate/Tonne in HK$	Total Cost
Total area of column = 450 m^2	45 tonne	5,520	249,000
Total area of wall = 3,150 m^2	275 tonne	5,400	1,458,000
Total area of beam = 1,004 m^2	195 tonne	5,650	1,101,750
Total area of cantilever beam = 129 m^2	75 tonne	5,750	431,250
Total weight of mild steel used	**590 tonne**	Total cost of material	3,240,000*

Note: *This figure is provided by the Kowloon Bay School main contractor which is rounded up to HK$100,000 due to commercial reason.

Other than large panel steel formwork, some conventional timber formwork was also used in staircases and areas where the structural members were of longer spans. To maintain the planned 12-day working cycle for each typical floor, two sets of convention formwork covering the long span areas and staircases with dead prop devices were required.

The quantity of timber used in the conventional formwork portion of the superstructure was measured as follow:

Area of long span and staircases: Two sets of formwork for slab and beam similar to Lam Tin school.
18 mm thick plywood: **940m^2**
50 mm x 100mm soft wood swan timber: 7600 m run, i.e. **40m^3**

2.2.5 Financial Cost

Similar to the conventional timber formwork subcontracting system, the main contractor of the Kowloon Bay School project subleted the formwork subcontract to a system formwork subcontractor. The subcontract work included the secondary school but cost of the secondary school was carefully taken out from this study. The following figures covered only the 30-classroom and the 24-classroom primary schools. The material used associated with the 24-classroom primary school was separated proportionally. This enables an direct comparison between the conventional timber formwork system used in the Lam Tin School and the large panel steel formwork and pre-cast semi-slab unit used in the Kowloon Bay School.

The cost information shown hereunder had been rounded up to HK$100,000

Table 8 Comparison of Total Cost of Formwork

	Description	24-Classroom Primary School	30-Classroom Primary School	Total
1	Cost of material for system formwork (one set of formwork for two schools)	HK$1,530,000	HK$1,710,000	HK$3,240,000
2	Cost of pre-cast unit semi-slab	HK$1,777,000	HK$2,638,000	HK$4,460,000
3	Cost of conventional timber formwork portion	HK$340,000	HK$400,000	HK$740,000
4	Cost of installation of system formwork	HK$4,590,000	HK$5,130,000	HK$9,720,000
5	Cost of installation of pre-cast unit	HK$1,600,000	HK$2,020,000	HK$3,620,000
6	Total Cost	HK$9,837,000	**HK$11,943,000**	HK$21,780,000

3. Comparison of Materials Used and Costs

3.1 Comparison of Material Used

The material used is compared between the two 30-classroom primary schools (the material used in the 24-classroom primary school in Kowloon Bay is excluded).

Material	Lam Tin School	Kowloon Bay School	Difference
Plywood	8,808 m^2	940 m^2	**7,868 m^2**
Softwood sawn timber	367 m^3	40 m^3	**327 m^3**
Mild Steel	N/A	590 tonnes	**590 tonnes**

3.2 Comparison of project duration

The time spent on both schools were similar. The working cycle per floor for the Lam Tin School was 11 days and for the Kowloon Bay School was 12 days. Since the schools were of eight stories high, the total time difference was 8 days. Taking into account of site cleanliness, the lesser amount of time spent on site cleaning of the residue timber in the Kowloon Bay School overcompensated the 8 days difference.

3.3 Comparison of Cost

Nature of Subcontract	Lam Tin School	Kowloon Bay School
Supply of Labour & Material	HK$5,268,620	HK$11,934,000

The cost attributed to the pre-cast concrete semi-slab should be deducted by the cost of equal volume of equivalent grade (30/20) of ready mixed concrete.

Assembly Hall/Special Room Block (5 story)		30 m^3
Class Room Block (8 story)		50 m^3
	Total:	80 m^3 @ HK$450/$m^3$

The cost of ready mixed concrete was HK$450x80=HK$36,000 for pre-cast semi-slab panels.

The salvage value of the steel formwork was considered as scrap steel for recycling. The cost of scrap steel less transportation charge was HK$100/tonne. The salvage value was HK$100x590=HK$59,000.

Therefore the cost of using system formwork integrated with pre-cast semi-slab was HK$6,570,380 (11,934,000 – 5,268,620 – 36,000 – 59,000) higher than the conventional timber formwork.

3.4 Other Issues

According to the information given by the main contractor of the Kowloon Bay School, wastage of pre-cast concrete semi-slab was over 20% of the total quantity delivered to the construction site. The cause of such high wastage value was due to poor quality of supply and careless handling during the course of transportation and installation. Labour resources required to remove and replace the damaged semi-slab with new one was high. The total volume of damaged pre-cast semi-slab became C&D waste was estimated to be 16 m^3 (20% of 80 m^3).

4. Conclusion

Based on the comparison of the cost and resources used for the two formwork systems, for the described school projects, the conventional timber formwork system was more economical. However, timber material consumption for the conventional timber formwork system was high and environmentally undesirable.

But large panel formwork can be repeatedly used for over 100 times. If the metal formwork could be used in other standard primary school projects, an economic advantage would be realized. According to the concreting cycle described in the case study, the formwork had been used for only 35 times. The formwork can be extensively used for more school projects of the same design to increase its economic advantage. It is suggested that in order to encourage the use of the low-waste construction method, priority for bidding school construction contracts could be given to those contractors who owned or are willing to use second hand large panel system formwork.

It is also noticed that environmental advantages warrant the use of system formwork over timber formwork. The economic disadvantage would be overcome when the repetitive usage cycle is extended especially for high-rise building construction.

Acknowledgements

The authors would like to express their sincere thanks to the following persons for providing valuable information for this study.

Mr. Percy Lau and Mr. Sunny Chan of Chevalier (Construction) Co., Ltd.
Mr. Simon Lee and Mr. Andrew Ip of China Civil Engineering Construction Corp.
Mr. C. K. Chan of Loyal Eastern Ltd.
The financial support of the Hong Kong Polytechnic University is also acknowledged.

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