Activities Sequencing for Housing Construction in Hong Kong

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INTRODUCTION

Different forms of construction techniques are, fundamentally, organizational devices used for economic reasons. They vary with the availability and the relative costs of resources, especially of labor and methods, and develop for reasons of economy of time, labor, and materials (Yau).

Public housing flats account for 46.2 percent of permanent living quarters in Hong Kong (HKSAR Government, 1999). The design of public housing blocks has been gradually standardized and modularized in recent years and it has lead to the development of Harmony Blocks and Concord Blocks. The Harmony Blocks, for example, make full use of modularization and standardization of building design and these facilitate the use of different advanced construction methods such as prefabrication and large panel formwork systems.

Standardized building design of Harmony Blocks makes its construction process rather typical compared with the private housing development. Its highly repetitive construction process generally requires only four to 10 days to complete one construction cycle. The significant difference of its construction cycle is mainly attributable to the adoption of alternative construction methods and the addition of physical resources such as labor and plant.

Through analyzing the design and construction methods of the Harmony Blocks, the logical sequence of operational construction works can be systematically formulated and an optimal construction method can be chosen with particular respect to the features, constraints, the availability of resources and the construction methods of different building components.

DESIGN OF HARMONY BLOCKS

The first Harmony Block building contract was commenced in late 1989 and completed in late 1992 (Hong Kong Housing Authority, 1993). The design of the Harmony series of standard blocks has adopted an approach of modular and dimensional coordination based on improved standards of space requirements for the living and service areas. A coordination grid has been established which includes structural zones, spaces and storey heights, along with key dimensions and various standard component details.

Modular Flats

Solutions for 1-bedroom (1B), 2-bedroom (2B), 3-bedroom (3B) and 1-person (1P) flats have been developed and by combining these standard modular flats (Table 1), various building forms/options together with the opportunity of different flat mixes are available which, in turn, generate different Harmony Blocks such as Harmony 1, Harmony 2, Harmony 3 (Figure 1 to Figure 3) and Harmony R. Generally speaking, Harmony R is designed for rural areas and its design varies from project to project; in view of its limited usage, its design will not form part of this discussion.

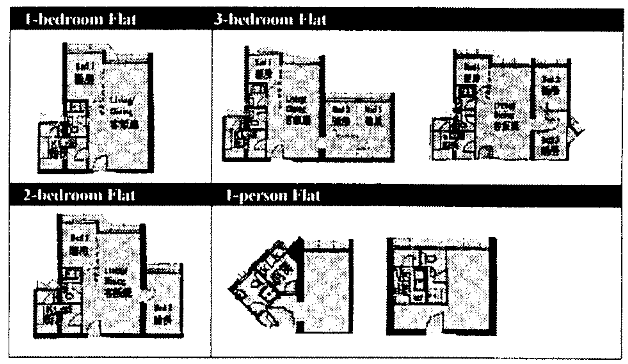


Table 1: Design layout of modular flats

Through the design of these modular flats, it is possible to standardize many of the building components, namely, external facades, staircases, floor slabs as well as loadbearing and non-loadbearing walls. Standardization of building components thereby enables fabrication of these components off-site allowing greater scope of quality control in the whole process of production. In addition, modularization of flats enhances the degree of interchangeability of building components within the Harmony Blocks construction. Because of this repetitiveness of modular flats, the system formwork can be deployed and transferred from one wing to another and the number of prefabricated components can also be reduced to a small number of types.

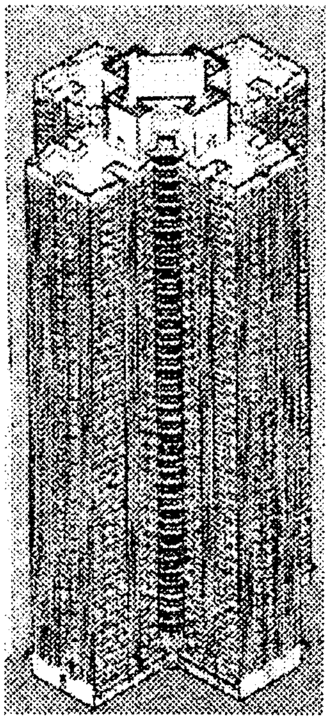
The typical sizes of different modular flats are listed in Table 2 for reference.

Harmony Blocks

Harmony Blocks are standard housing towers designed to be constructed on a repetitive basis at various sites throughout the Territory of Hong Kong. In view of this, different design options are

Type of Modular Flats	Saleable Floor Area (m^2)	Gross Domestic Floor Area (m^2)
1-bedroom flat (1B)	39.9	53.5
2-bedroom flat (2B)	49.7	66.6
3-bedroom flat (3B)	55.5	74.4
1-person flat (1P)	19.7	26.4

Table 2: Typical flat sizes for modular flats of Harmony Block (Hong Kong Housing Authority, 1996)



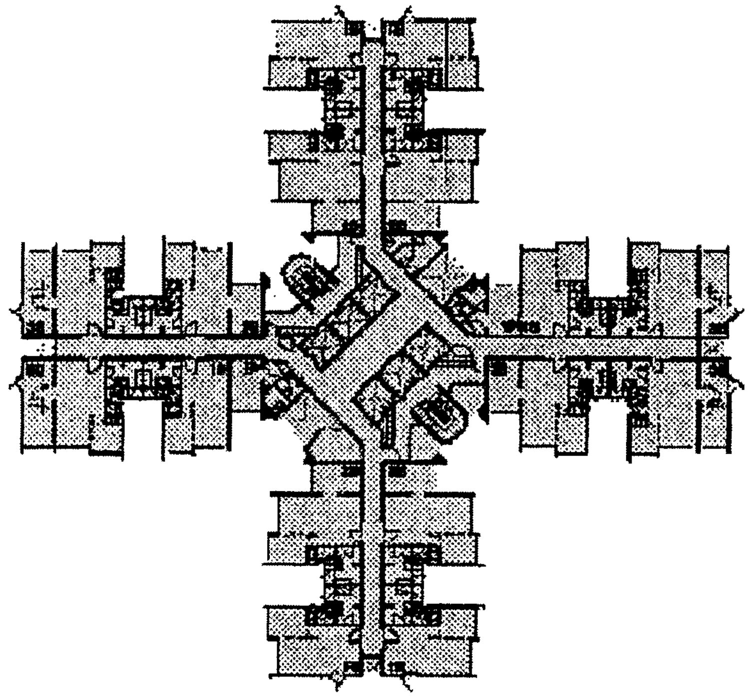


Figure 1: Design of Harmony 1 housing block

available for Harmony Blocks and for modular flats. For instance, there are five options available for Harmony 1 Block (Figure 1).

Where possible, wall sections and slab soffits have been maintained as plain surfaces to facilitate the use of large panel formwork system. To complement this, the internal walls forming the kitchens and bathroom areas, and the external facade panels to the living and bedroom areas are non-structural elements, which may be added at any stage in the construction process. In other words, the construction process for these elements is not critical.

The internal non-structural walls are constructed of full height precast partition panels, 75mm, 100mm or 150mm thick as required. They are installed manually and are capable of receiving emulsion paint finish or tiles fixed with approved adhesive, thus eliminating the wet trade applications and reducing site labor content.

Harmony Block is a reinforced concrete building structure designed to act as a fully integrated unit from the viewpoint of structural design. The lateral stability of Harmony Block structure is provided by shear walls and cores acting in conjunction with floor slabs and beams. Then the lateral loads are transferred to the foundations. The floor slabs are designed as one-way or two-way spanning plates supporting by the shear walls.

Harmony 1 Block (Fig. 1) comprises 38 or 40 domestic levels of typical design with the ground-floor non-domestic storey designed to accommodate ancillary facilities. The 16 to 20 modular flats per floor are arranged in four groups in a cruciform configuration attached to the central core where building services, lifts, and staircases are located. This configuration satisfies the maximum travel distance of 36m within which not more than 24m shall be along a corridor (Building Ordinance Office, 1986).

Public areas on each floor such as lift lobbies and corridors are designed for maximum natural lighting and ventilation. All the corridors have been designed with open ends to meet this purpose and improved measures of security.

The compact form of Harmony 1 Block makes it suitable for use in smaller urban area redevelopment sites. Its rectangular shape also fits into the rectilinear grid of urban area and integrates well with the surrounding buildings.

Harmony 2 (Fig. 2) comprises three wings of 36 or 40 domestic levels radiating at 120 degrees to each other from the central core where building services, lifts and staircases are located. The 18 to 21 modular flats per floor are arranged in three groups as a trident configuration.

Derived from the modular flat design, all flat units are grouped in three identical wings. This arrangement, in large panel construction terms, enables rotational and repetitive use of formwork without the need to ground any formwork not being used in the next concrete pour.

The flat layout at the middle of the wing allows considerable flexibility of flat mixes. The 3-bedroom/1-bedroom (3B/1B) combination is easily converted to 2-bedroom/2-bedroom (2B/2B) or 1-bedroom/1person/1-bedroom (1B/1P/1B) combinations to suit different planning brief requirements. The configuration of Harmony 2 Block is most suitable for use in large suburban area sites.

Harmony 3 (Fig. 3) with a maximum of 31 storeys (30 domestic floors) is designed to complement the Harmony 1 and Harmony 2 Blocks and to recognize the particular needs of height restrictions, restricted site conditions and specific needs of redevelopment sites. To fulfill these aims by using the standard modular flats, a "flexible" building design is introduced and it comprises two major elements, **service module** and **flexible wing**.

The flexible wing is capable of rotation around the service module at pre-determined angles. With optimized circulation and servicing, this concept enables forms adaptable to the varying sizes and shapes of the site, giving the opportunity to complement the geometry of Harmony 1 and Harmony 2 Blocks and optimize the site layout and land use potential.

Contract Period for Harmony Block Construction

The contract period for one 41-storey (40 domestic floors) Harmony 1/Harmony 2 Block is shown in Table 3 (Hong Kong Housing Department, 1996 and 1994). The contract period for the full height 31-storey Harmony 3 is shown in Table 4 (Hong Kong Housing Department, 1997).

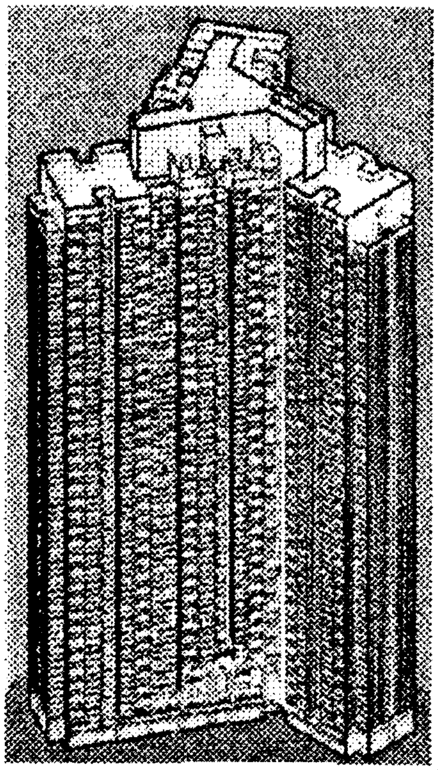
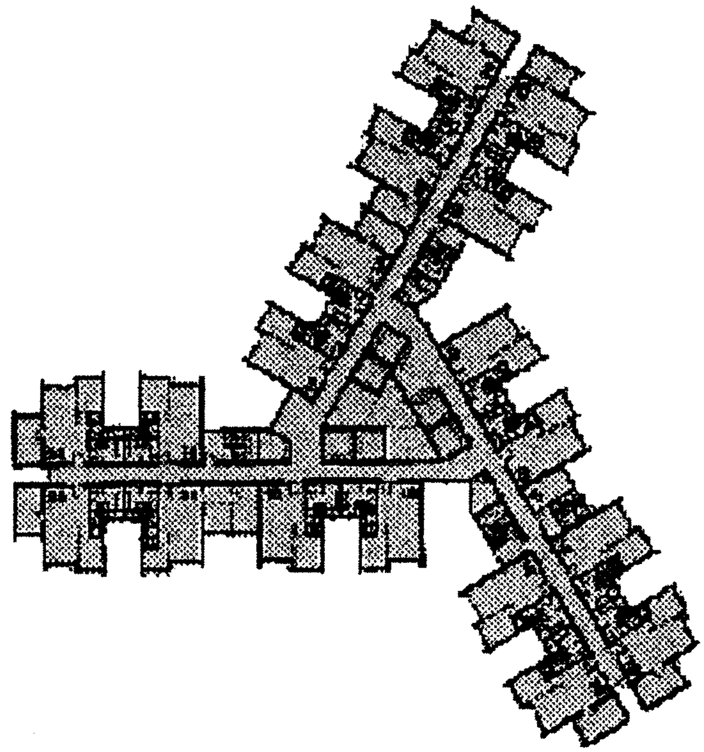


Figure 2: Design of Harmony 2 housing block



Major Activities	Months
1. Piling and pile caps	9
2. Mobilization and setting out	1
3. Ground floor construction	2
4. Typical floors construction (F1-F40)	12
5. Main roof construction	1
6. Upper roof construction	1
7. Lift installation and finishing work	9
Total	35

Table 3: Contract period for Harmony1/Harmony 2 block

Major Activities	Months
1. Piling and pile caps	9
2. Mobilization and setting out	1
3. Ground floor construction	2
4. Typical floors construction (F1-F30)	9
5. Main roof construction	1
6. Upper roof construction	1
7. Lift installation and finishing work	8
Total	31

Table 4: Contract period for Harmony 3 Block

The contract periods shown above allow no mechanical working on Sundays and Public Holidays. For internal planning purposes, the total construction period allows for a two-month Extension of Time for inclement weather on top of the contract period.

Table 3 and Table 4 show that a period of 12 months is required for constructing a 40 typical floors of Harmony 1/Harmony 2 Block; whereas nine months for a typical 30 floors of Harmony 3 Block. In other words, one typical floor has to be completed within nine days as stipulated (12 months x 30 days = 40 floors for Harmony 1/ Harmony 2 Block, and 9 months x 30 days = 30 floors for Harmony 3 Block).

Methods of Constructing Harmony Blocks

Besides traditional construction by timber formwork, various methods have been introduced for constructing the reinforced concrete structural frame of Harmony Blocks in recent years in order to strive for better quality, enhanced construction process, cost effectiveness and efficiency of production. These advanced methods can be grouped by the method of construction.

1. Large Panel Formwork Systems
- Wallform
- Tableform

2. Precast Components
- Precast Facade
- Precast Partition Wall
- Semi-precast Slab
- Precast Staircases

With the mandatory requirement of using large panel formwork for wall construction as stated in the General Specification (Hong Kong Housing Department, 1989), Harmony Blocks can generally be built with the following combination of building techniques (Table 5)

By combining these building techniques in various degrees and scheduling their activities sequencing, different construction cycles and floor cycles can be achieved in order to satisfy the specific project requirements on time, cost and quality. For instance, constructing a typical Harmony 1 Block with wallforms, tableforms, precast staircases and precast facades generally requires nine days to complete one construction cycle; whereas with wallforms, semi-precast slabs, precast staircases and precast facades generally requires six days to complete one construction cycle. Besides, the construction cycles and floor cycles differ with the design of Harmony Blocks, as illustrated in their respective method statements for construction.

Major Building Components	Alternatives											
	1	2	3	4	5	6	7	8	9	10	11	12
Domestic Walls	Wallform											
Walls (Lift Core)	Wallform											
Partition Walls	Precast											
Domestic Slabs	Timber Formwork				Tableform				Semi-precast			
Slabs (Corridor and Lift Lobby)	Timber Formwork											
Façades	T	P	T	P	T	P	T	P	T	P	T	P
Staircases	Timber		Precast		Timber		Precast		Timber		Precast	

Table 5: Different combination of building techniques for constructing Harmony Blocks (T - Timber Formwork; P - Precast)

METHOD STATEMENTS FOR CONSTRUCTING HARMONY BLOCKS

Method statements (The Chartered Institute of Building, 1991) can take one of two forms: A detailed record of the calculation and assumptions made in the preparation of a programme; construction methods, production output levels, resource levels; or a broader description of the intended method of carrying out a project. In Hong Kong, method statements for construction are generally submitted for those specialized and sophisticated works such as the top-down building construction, curtain wall construction and precast facades installation. Although a public housing project is typical and repetitive in nature, the clear understanding of the construction activities and their sequencing is vital to the success of the project, particularly with the emphasis of reducing the construction period. In view of this, the method statement which provides a comprehensive appreciation of the way the contractor intends to manage and execute a project is widely adopted as part of the tender bid submission and as a procedure manual for the structural frame construction.

In fact, method statements are increasingly demanded by the developers, including the major property developer in the territory—Hong Kong Housing Authority—at the pre-tender stage as a means of shortlisting contractors eligible to tender for a building project. Besides, a wellprepared method statement for work implementation will provide a blueprint against which the success of the work can be judged (Works Branch, 1996). For these reasons, considerable efforts and cost are devoted to the preparation of method statements.

Method statements can be presented in the form of a descriptive essay, in bullet form or in tabular form. In descriptive essay form, information regarding the method of construction is described in detail whereas in tabular form, information is distinctively grouped under different headings for easy reference. However, method statement in bullet form is commonly used in the Hong Kong Construction Industry for its ease of writing up. For ease of reference, method statements for typical activities involved in the construction of major building components of Harmony Blocks are expressed in bullet form. Method statements include:

Structural walls construction (including domestic and lift core)

1. Setting out of walls at N floor in Wing A
2. Fix steel reinforcement for walls at Nth floor in Wing A
3. E&M installation for walls at N floor in Wing A
4. Erect metal wall formwork at N floor in Wing A
5. Pour concrete to walls at N floor in Wing A
6. Dismantle metal wall formwork at N floor in Wing A
7. Rotate metal wall formwork at N floor in Wing A to Wing B and then Wing C to Wing D
8. Move metal wall formwork to N floor in Wing D to (N+1)floor in Wing A
9. Repeat the Step 1-8 after completion of slab construction at (N+1) floor in Wing A

Partition walls construction

1. Setting out of the partition walls at (N-m) floor in Wing A, where N>m and m≠0
2. Erect precast partition wall panels at (N-m)floor in Wing A, where N>m and m≠0
3. Repeat the Step 1-2 at (N-m+1) floor in Wing A, where N>m and m≠0

Domestic floor slabs construction

Timber Formwork

1. Erect timber slab formwork at N floor in Wing A
2. Fix steel reinforcement for slabs at N floor in Wing A
3. E&M installation for slabs at N floor in Wing A
4. Pour concrete to slabs at N floor in Wing A
5. Dismantle timber slab formwork at N floor in Wing A
6. Install temporary supporting system to slabs at N floor in Wing A
7. Move timber slab formwork to (N+1)floor in Wing A
8. Repeat the Step 1-7 after completion of wall construction at (N+1) floor in Wing A

Tableform

1. Erect metal slab formwork at N floor in Wing A
2. Fix steel reinforcement for slabs at N floor in Wing A
3. E&M installation for slabs at N floor in Wing A
4. Pour concrete to slabs at Nfloor in Wing A
5. Dismantle metal slab formwork at N floor in Wing A
6. Install temporary supporting system to slabs at N floor in Wing A
7. Move metal slab formwork to (N+1) floor in Wing A
8. Repeat the Step 1-7 after completion of wall construction at (N+1) floor in Wing A

Semi-precast

1. Install temporary supporting system to slabs at N floor in Wing A
2. Install semi-precast slabs at N floor in Wing A
3. Fix steel reinforcement for slabs at N floor in Wing A
4. E&M installation for slabs at N floor in Wing A
5. Pour concrete to slabs at Nth floor in Wing A
6. Repeat the Step 1-5 after completion of wall construction at (N+1) floor in Wing A

Non-domestic floor slabs construction (including corridor and lift lobby)

Timber Formwork

1. Erect timber slab formwork at N floor in Wing A
2. Fix steel reinforcement for slabs at N floor in Wing A
3. E&M installation for slabs at N floor in Wing A
4. Pour concrete to slabs at N floor in Wing A

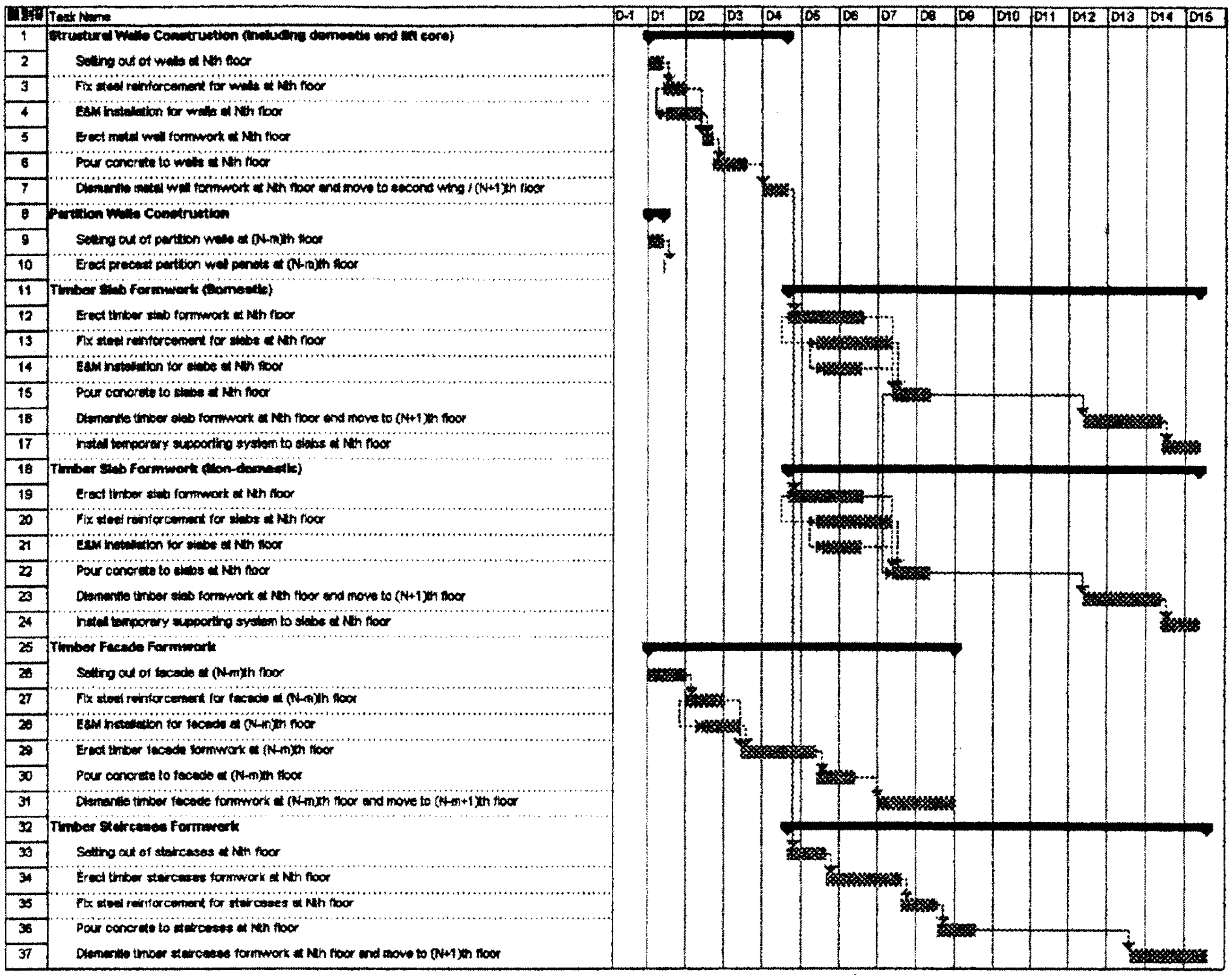


Figure 4: Sequencing for constructing Harmony Block with "Alternative 1" (9-Day Construction Cycle) - Alternative 8

5. Dismantle timber slab formwork at N floor in Wing A
6. Install temporary supporting system to slabs at N floor in Wing A

Move timber slab formwork to (N+1) floor in Wing A

Repeat the Step 1-7 after completion of wall construction at (N+1) floor in Wing A

Facade construction

Timber Formwork

1. Setting out of facades at (N-m) floor in Wing A, where N>m
2. Fix steel reinforcement for facades at (N-m) floor in Wing A, where N>m
3. E&M installation for facades at (N-m) floor in Wing A, where N>m
4. Erect timber facade formwork at (N-m) floor in Wing A, where N>m
5. Pour concrete to facades at (N-m) floor in Wing A, where N>m
6. Dismantle timber facade formwork at (N-m) floor in Wing A, where N>m
7. Move timber facade formwork to (N-m+1) floor in Wing A, where N>m
8. Repeat the Step 1-7 after completion of slab construction at (N-m+1) floor in Wing A, where N>m

Precast

1. Install precast facades at (N-m) floor in Wing A, where N>m
2. Repeat the Step 1 at (N-m+1) floor in Wing A, where N>m

Staircases construction

Timber Formwork

1. Setting out of staircases at N floor
2. Erect timber staircases formwork at N floor
3. Fix steel reinforcement for staircases at N floor
4. Pour concrete to staircases at N floor
5. Dismantle timber staircases formwork at N floor
6. Move timber staircases formwork to (N+1) floor
7. Repeat the Step 1-6 after completion of slab construction at (N+1) floor

Precast

1. Install precast staircases at N floor
2. Repeat the Step 1 after completion of slab construction at (N+1) floor

Activities Sequencing

Depending on the different combination of building techniques and the corresponding constraints governing the overall construction duration, the content of method statement for a particular project varies, particularly the activities sequencing, as illustrated in the following sample Gantt Charts for constructing Harmony Blocks. Figure 4 to Figure 7 show the adoption of Alternative 1, 8 and 12 with different construction cycles for constructing a typical Harmony Block.

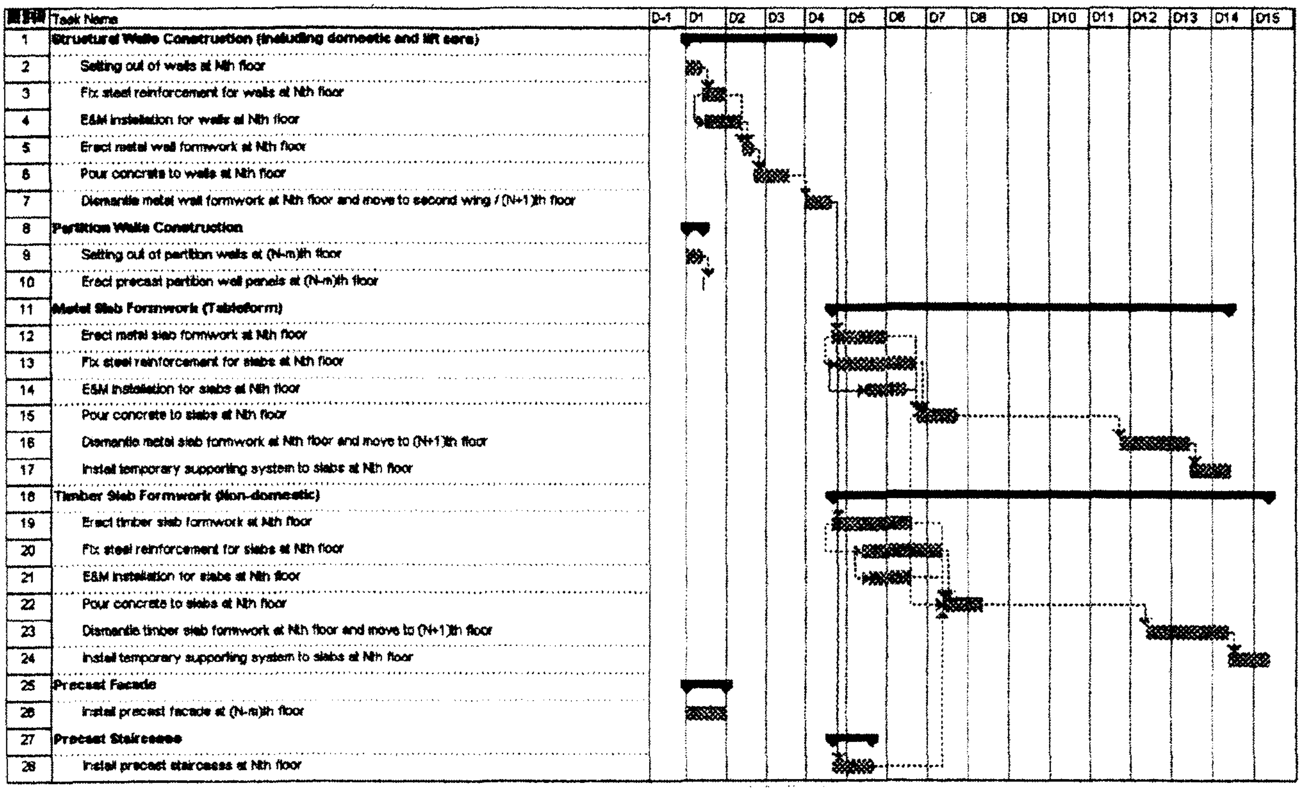


Figure 5: Sequencing for constructing Harmony Block with "Alternative 8" (8-Day Construction Cycle)

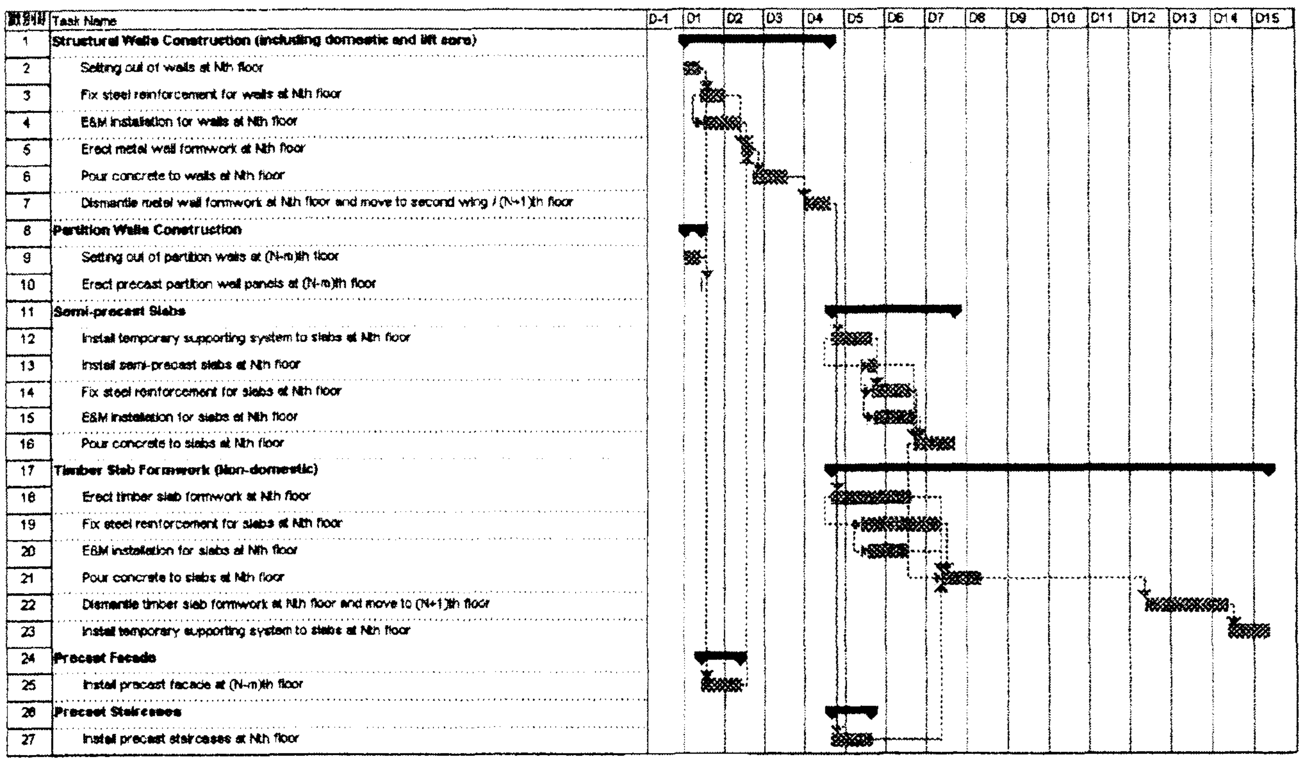


Figure 6: Sequencing for constructing Harmony Block with "Alternative 12" (8-Day Construction Cycle)

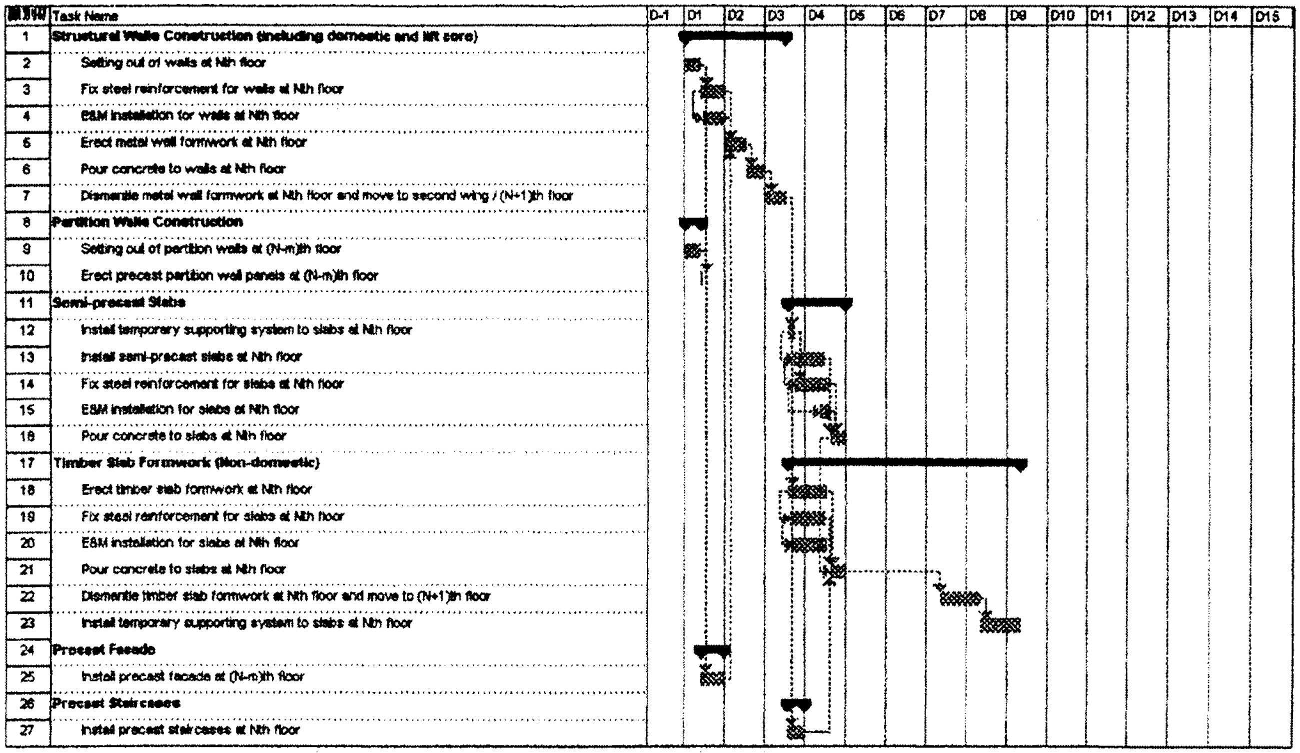


Figure 7: Sequencing for constructing Harmony Block with "Alternative 12" (4-Day Construction Cycle)

RATIONALES FOR DIFFERENT ACTIVITIES SEQUENCING

Various combinations of different building techniques and input of resources for the construction of Harmony Blocks result in different sequences of construction activities with different construction cycles. The difference in activities sequencing and construction cycles as illustrated Figures 4 to 7 are mainly attributable to the following factors:

Construction Methods

Depending on the specific requirements on time, cost and quality for the construction of housing blocks, different construction techniques will be deployed for the construction of major building components. Generally speaking, mechanization which adopts mechanized construction methods such as large panel formwork and tower cranes, and, prefabrication which transfers the construction of complicated components from site to factory have effected in substantial savings in skilled on-site labor, expedition of the construction and better quality products rather than that of tradition timber construction.

As illustrated in Figures 4 and 5, the difference in construction cycles is mainly attributable to the construction of staircases and facades. Using precast staircases and facades, instead of timber formwork for construction, will expedite the construction by reducing the works on site and putting these activities as non-critical. For the construction of domestic slabs, metal slab formwork allows shorter construction duration than that of timber slab formwork because the time spent in assembling and striking formwork is much less than that required by the timber slab formwork. Besides, using metal slab formwork which is one of the large panel formwork will eliminate the common deficiency of timber slab formwork like stepped joints, grout leakage, plywood pealing off, bulging of concrete surfaces, etc. (Mak, 1998).

Performance Requirements

The most influential factor affecting the construction cycle is the performance requirements of concrete components, particularly for the in-situ concrete construction. For the formwork construction, there are statutory requirements on the minimum period which must elapse before formwork may be removed (Building Construction Regulations, 1997). These ensure the final concrete structure shall support safely the combined effects of all loads and within the limits of acceptable dimensional tolerances. Taking structural walls construction and slab formwork construction as examples, they shall not be dismantled until 12 hours and four days were elapsed upon concreting respectively as illustrated in Figure 6.

To shorten the minimum period before striking formwork, higher strength of concrete than that required by the statutory (Building Construction Regulations, 1997) can be deployed for better durability and high early strength. In Figure 7 , Grade 35/20 concrete was used for the construction of slabs to achieve a minimum of 10MPa and 20 MPa cube strength for 1-day and 3-day age respectively as compared with Grade 30/20 concrete normally used for domestic building.

Machinery

Not until 1981 (Construction & Contract News, 1983) did the Housing Department stimulate the use of semi-mechanized and fullymechanized systems for housing construction in the Housing Authority projects, then the local building contractors recognized the benefits of using more advanced techniques in building projects, with particular reference to the improvement in the quality of works and stringent demand on skilled labors. Since then, the labor-intensive works such as using timber formwork, propping, material hoist, scaffolding, trolleys for concreting were largely replaced by the large panel formwork, tower cranes, concrete batching plant, concrete pumps and gondola. Today, contractors are mandatorily required to deploy tower cranes, large panel formwork and concrete batching plant in the construction of typical housing blocks.

In Figure 6, concrete topping to the semi-precast slabs is delivered by tower crane and skip whereas, in Figure 7, concrete is delivered by concrete pump. In this way, no only the time spent in delivering concrete is shortened, but also the craneage is substantially reduced. In fact, the use of concrete pumps reduces the demand on the tower crane by approximately 40 percentage of craneage (Chan and Lee, 1998).

Input of Resources

The use of large panel formwork and prefabrication obviously requires the use of tower crane for the vertical and horizontal transportation of concrete, reinforcement, formwork and precast components. As a result, the tower crane becomes a critical mechanical plant governing the duration of construction works. For ease of site layout planning and economic reasons, one tower crane will normally be erected for the construction of a typical housing block. However, in order to reduce the average craneage and accelerate the relevant construction works, more tower cranes (e.g. three housing blocks with four tower cranes) are inevitable.

Harmony blocks comprise three to four wings and each wing has its own construction cycle. Combining these construction cycles will form the floor cycle for the particular housing block. In the example of Figure 7, one wing set of typical large panel formwork was employed and could be transferred from one wing to another for the construction of structural walls. Roughly speaking, it achieves a four-day construction cycle with a 11.5-day floor cycle for a typical Harmony 1 housing block. The floor cycle can be expedited to 6.5 days and four days by employing one or three more wing sets of large panel formwork. However, it may not be economical to employ more than one wing set of large panel formwork for the "cyclical" construction of structural walls because the overall construction duration of a typical housing block is only accelerated by 5 days and 11.5 days when one or three more wing sets of large panel formwork are used.

Therefore, the common practice of accelerating the construction cycle is to increase the driving resources such as additional formworkers and steel benders which can shorten the duration of construction works.

CONCLUSIONS

The shift of housing policy from quantitative emergency relief and squatter clearance to a more quality oriented approach since 1972/73 urged for a shorter development period for housing block without scarifying the quality of work. The situation is more obvious due to the increasing supply of housing units over the next decade as pledged by the Hong Kong Special Administrative Region (HK SAR) Government (HK SAR Government, 1997, and Tung, 1997). To fulfill these requirements, an obvious solution seems to be the addition of physical resources such as additional tower cranes, concrete pumps and slab formwork. However, not all of the resources are driving resources. Besides, adding resources will reduce the contractorís profit margin and even adversely affect the construction sequences, especially for those on congested sites. For example, an additional tower crane may, to a certain extent, accelerate the vertical transportation of materials but it may restrict the scope of horizontal transportation of materials in a restricted site, let alone lead to a reduction of the useable working area.

It is for this reason that an in-depth study of the existing construction methods for housing construction has been made, with particular emphasis on the repetitive construction activities such as timber formwork for slab construction. By combining different construction techniques in various degrees and scheduling their activities sequencing at the planning stage, an optimal construction cycle and floor cycle can be easily achieved for the project while meeting specific requirements on time, cost and quality.

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