Precast Concrete — Solution of Choice for Upgrading Public Housing in Singapore

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The Housing and Development Board (HDB) of Singapore has gained worldwide recognition for setting high standards in public housing. To date, 87 percent of Singapore's 3 million citizens reside in high rise public apartment blocks. More than 80 percent of these apartments are owned by the residents. In 1989, the government of Singapore, through the HDB, embarked on an ambitious program to upgrade the quality of existing stocks of public housing. This paper discusses how prefabrication technology is being used to overcome the many difficulties associated with the construction of high rise apartment extensions in heavily populated areas as part of the upgrading program. The various types of precast concrete systems, used with fundamental guidelines on design for cost effectiveness and buildability, are also presented.

The Housing and Development Board (HDB) is the sole public housing authority in Singapore and is responsible for providing high quality housing for its people at affordable prices. Since its inception in 1964, the HDB is credited with constructing more than 750,000 apartments, housing approximately 86 percent of Singapore's population, in many estates spread over the island. In recognition of its achievements, the HDB has won many awards, the most significant being the distinguished United Nations World Habitat Award for 1991.

The estimated number of apartments separated into various age groups is listed in Table 1. The government had at the onset decided to fix the size of the upgrading program by pegging it against the number of apartments as of 1993. About 80 percent of these apartments were owned by the residents at the time.

The purpose of this paper is to share HDB's experience in the design and construction technology aspects of providing additional high rise space to existing buildings in Singapore's Public Housing Upgrading Program. Cost-effective systems based on the use of

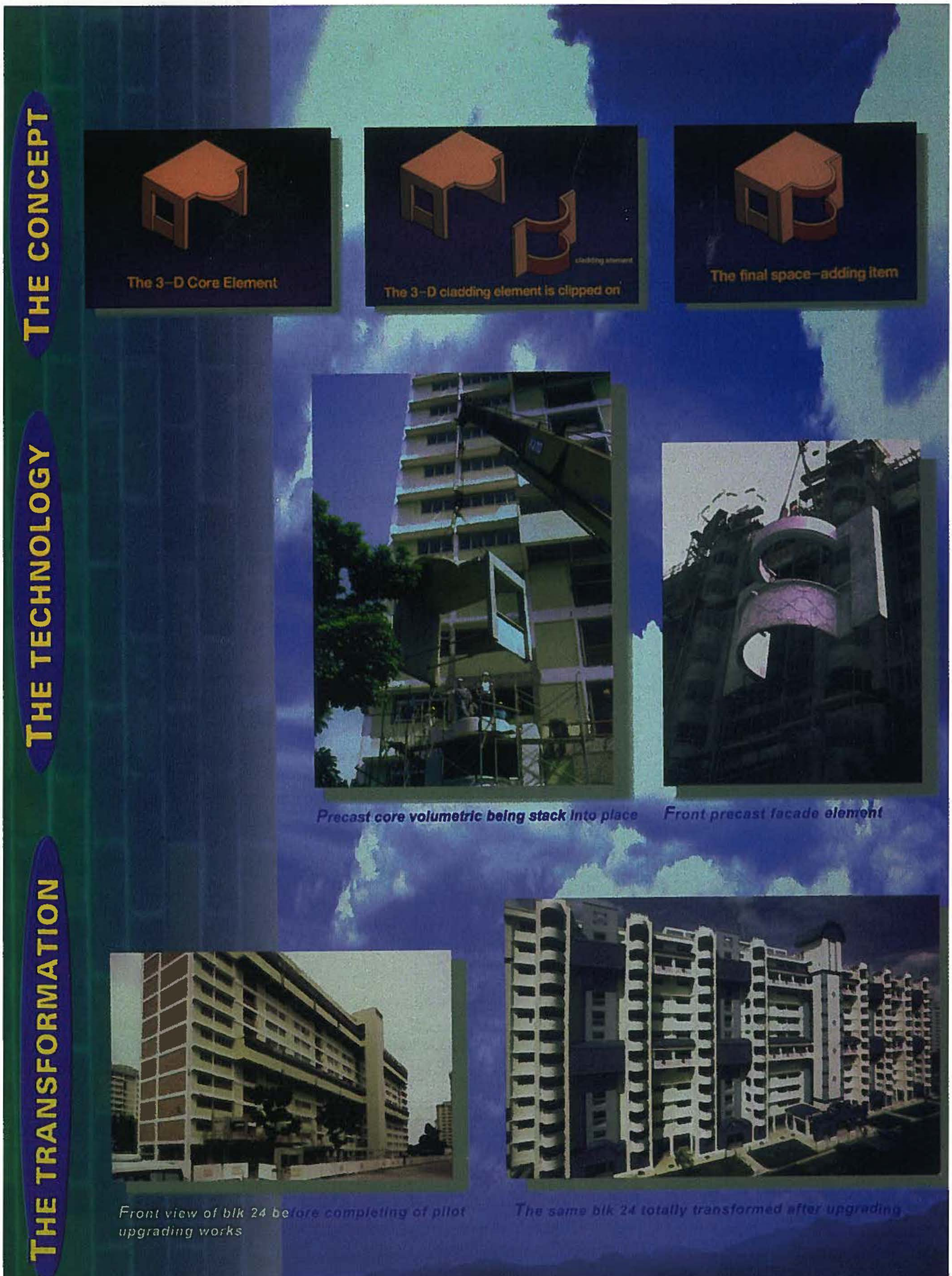
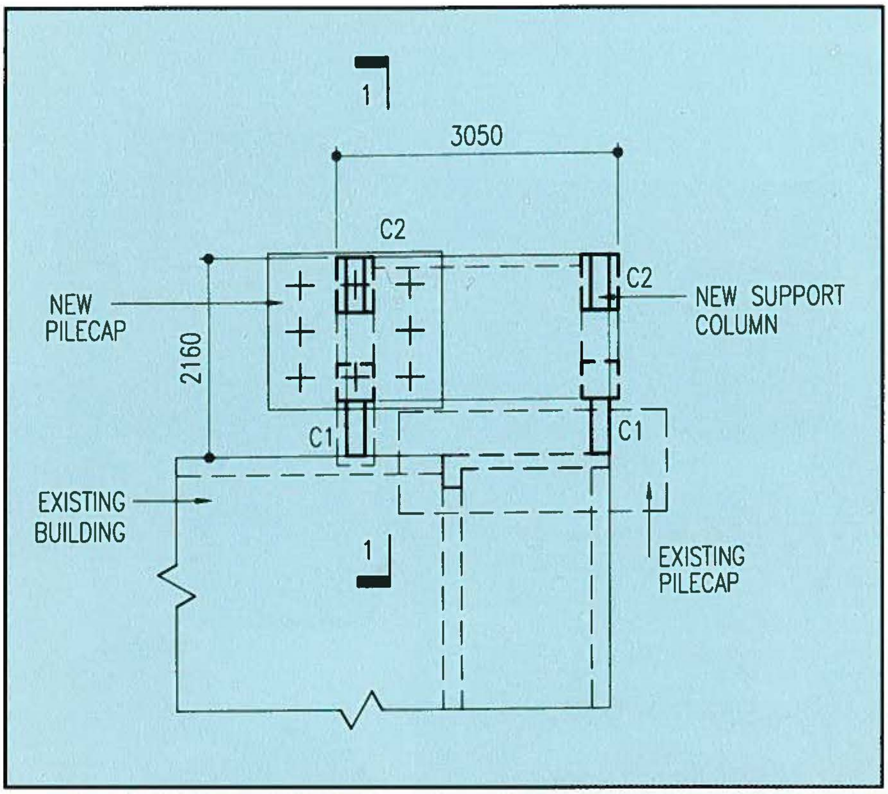


Fig. 1. Prefabrication solution for developing additional space in public housing upgrading program (Teban Gardens).



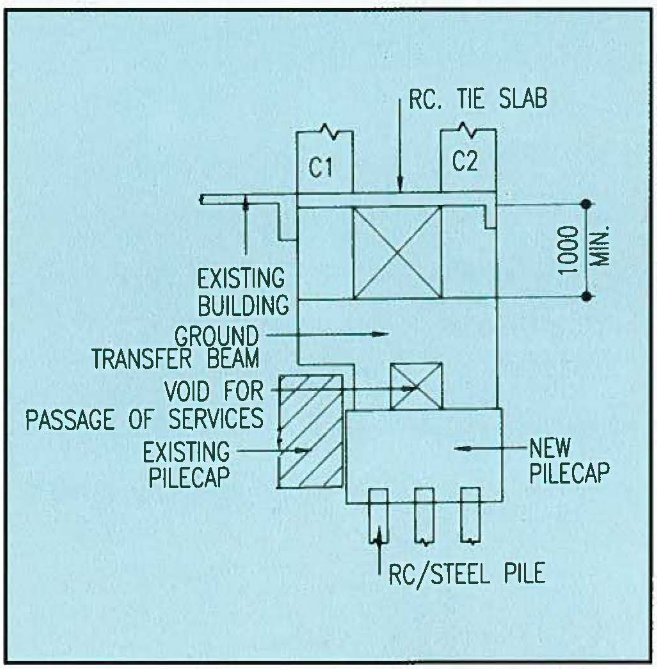


Fig. 2. Plan view and section of new foundation for typical added space stack.

large precast concrete volumetrics have been used successfully to overcome the special difficulties of construction work in congested and heavily populated areas. The authors hope that the contents of this paper will serve as a platform for further exchange of information and experiences for the mutual benefit of all housing authorities around the world.

RATIONALE FOR UPGRADING HOUSING

The last decade has seen rapid growth in the affluence of Singapore's population. Expectations in public housing have grown from that of a "roof over the head" priority to bigger, better designed and finished apartments served by a network of social amenities.

Table 1. Stratification of apartments according to age groups.

Age of apartments	Percentage of dwelling units in various age groups
Above 20 years	18 percent
15 to 19 years	24 percent
10 to 14 years	18 percent
Below 10 years	40 percent

This growth has been reinforced by the strong preference for housing in the newer and better designed estates. To check this trend, the government announced plans in 1989 for an ambitious program to upgrade all the older estates. The rationale for upgrading, as opposed to redevelopment, of old buildings can best be summarized as follows:

1. To upgrade the quality of the total living environment without uprooting and breaking up people from their familiar groups and to keep intact the fabric of the communities built on traditional Asian family values.

2. Demolition that comes with redevelopment of old apartment blocks would result in considerable social dislocation and inconvenience to residents. In land-scarce Singapore with only 600 km^2 (230 sq miles) of land as an asset, this would be a tremendous waste of resources.

3. Upgrading would bring the older estates closer to the standards of new HDB estates.

4. Upgrading would be an effective means through which the government can disburse back to the people a portion of the national wealth accrued since independence.

As a start, only apartments that are more than 10 years old will qualify for public housing upgrading. The result is that 370,000 apartments are scheduled for upgrading in the next decade.

SCOPE OF UPGRADING PROJECTS

In general, the areas needing structural upgrading in which engineering expertise is required are summarized below:

Within Buildings

1. Construction of new utility rooms, service and private balconies, toilet cubicles and any combination of the above. These are normally referred to as the "space adding" items (SAI).

2. Use of lightweight architectural claddings, providing a new "facelift" to the existing building facade.

3. Construction of new lift shafts or modification of existing ones with the primary objective of providing total accessibility to all floors of the apartment block.

4. Rerouting of electrical, gas and water lines through new external service duct box trunkings attached to the building facades.

Fig. 3. Foundation for added space showing ground transfer beam layout (Block 413 Clementi Estate).

Within Precincts

Construction of new multistory parking structures, community halls, electrical substations, dustbin compounds and social amenities.

SPECIAL CONSIDERATIONS FOR UPGRADING

In upgrading the older estates, several apartment blocks and the surrounding areas are clustered together to form a precinct. The construction, as discussed earlier, must be executed without displacing any of the residents.

The upgrading program in essence involves the participation of the residents from the conceptual design phase through construction and completion. The human element dictates and shapes the form of the building design and the construction technology to be used. The technology and construction methods have to be tailored to meet the following requirements:

1. Enhanced safety and security requirements for the residents coupled with stringent controls on noise and dust pollution arising from the construction site.

2. Dry construction processes that result in faster construction turnaround time to minimize the extent and duration of inconveniences the residents will have to tolerate.

3. Cost effectiveness, with the complexities of various technical, social, and budgetary constraints factored in.

The extensive use of prefabrication methods that hinge around offsite/online factory production techniques of building components fits ideally with the above requirements. At the same time, prefabrication also ensures better standards of construction workmanship and reduces considerably the dependence on imported goods and skilled foreign labor for the overall program.

IMPLEMENTATION PROGRAM

Despite HDB's 30 years of design and construction experience in public housing, the development of an engineered system for construction of the space added items was a formidable task. A trial period in which both tech-

Table 2. Typical operating parameters for various piling systems.

Piling system	Type of material	Size	Working load	Penetration depth range	Typical operating parameters
Jack-in	Reinforced concrete	150 x 150 mm section	16 tons	8 to 25 m	Used in soils with SPT less than 50.
Piling	Steel	200 x 200 mm H-pile section	30 tons	25 to 45 m	Used in soft soils, e.g., marine clay and where pile penetration exceeds 25 m.
Micropiling	Reinforced concrete	225 mm diameter bored pile	80 tons	8 to 25 m	Used when: (a) ground is stiff, i.e., when SPT is greater than 50; (b) driving of piles for new foundation is obstructed by extensive protruding foundation of abutting existing block.
Footing	Reinforced concrete	Nonstandard	—	—	Used when: (a) soil has bearing pressure of 15 tons/m^2; (b) column loading is 20 tons; (c) added space stack is less than four stories; (d) there is adequate space for construction of new footings.

Note: 1 mm = 0.039 in.; 1 m = 3.3 ft; 1 ton = 1.1 t; 1 ton/m^2 = 0.1 t per sq ft.

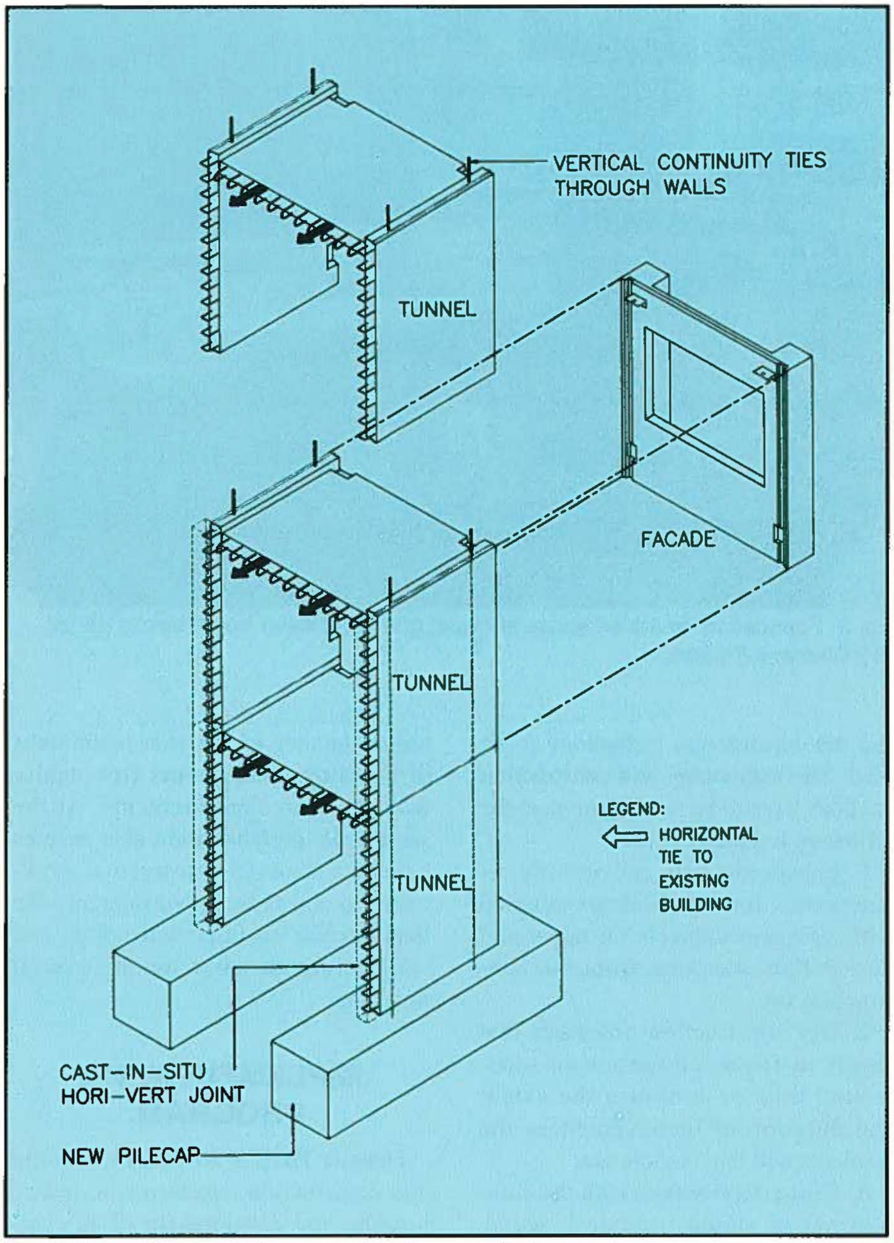


Fig. 4. Precast concept for new added space stack.

nical and administrative systems could be field tested and refined was essential. Given the complexity and size of the program, its implementation was carried out in three phases, namely, the pilot phase, demonstration phase and steady state upgrading phase.

Pilot Phase

This phase was carried out in two blocks of vacant apartments in the Woodlands and Teban Gardens Estate each. Prototype precast concrete designs together with pilot projects for the construction of the added space commenced in 1991 and were completed in 1993.

All systems were evaluated and the valuable feedback and experience served as the basis for launching the next phase of the program.

Demonstration Phase

This phase, consisting of six precincts and covering 41 blocks of apartments (6000 units), has been completed. The difference between the pilot and demonstration phases hinges on the conditions under which the added space structures were executed.

In the pilot projects, contact with the public was accomplished by several volunteer live-in families with the rest of the apartment blocks left completely vacant. In the demonstration phase, the contractors had to work in fully populated apartment blocks and, therefore, contact with the residents was inevitable. All this made possible yet another round of fine tuning of the design and construction systems.

Steady State Upgrading Phase

The development projects for the precincts under this phase started with the calling of bids for the Batch 1 to 6 precincts in April 1994. The program is estimated at about 15,000 units in the initial stages rising to about 20,000 by the year 2000. This steady increase had factored in all national resources to ensure that the program would not overburden the local construction industry.

BUILDABILITY AND AESTHETICS OF PREFABRICATION

The viability of the use of prefabrication in public housing upgrading hinges on ensuring that:

1. Component designs are kept simple and streamlined.

2. Standardization of precast concrete components is imperative.

3. There must be an optimum number of repetitions of components.

4. The size and weight of the components must be kept to a minimum.

The emphasis on standardization and component repetition does not conflict with the architect's requirements for aesthetics and flexibility of design. Prefabrication, when properly used, enhances buildability and aesthetics. The completed pilot project at Teban Gardens (see Fig. 1) reinforces this concept.

In public housing upgrading, because of the highly built-up nature of the existing sites, many designs for the added space that would have been difficult if not impossible to construct using conventional cast-in-place methods can be cost effectively constructed with the highest standards of workmanship using prefabrication. This, of course, is subject to the ability to achieve economies of scale in component construction.

Several factors that are direct manifestations of the special considerations for upgrading have reinforced the use of prefabrication in lieu of cast-in-place methods:

1. The typical floor area of each added space type ranges from 3.5 to 6 m^2 (37 to 65 sq ft). This places severe constraints on the number of workers from each trade that each added space level can safely and practically accommodate at any one time.

2. The requirement that all added space and other peripheral works in each block should be completed within a 16-month period.

The cost of constructing the 6 m^2 (65 sq ft) of added space varies from $250 to $300 per sq ft (in Singapore dollars), which is about four times what it would currently cost to construct a new block of apartments with conventional cast-in-place methods. This direct one-to-one comparison is, of course, not accurate. If cast-in-place methods had been used, the result would have been not only a longer construction turn-around time but also more noise and dust pollution. It is difficult to put a dollar value on such intangibles.

If the cost of cast-in-place methods is properly adjusted by factoring in all of these intangibles, the authors are confident that prefabrication will still be cheaper.

To date, with 28 contracts tendered out to HDB's credit, there has yet to be a counterproposal using the cast-in-place alternative. This is perhaps the strongest vindication of the authors' contention.

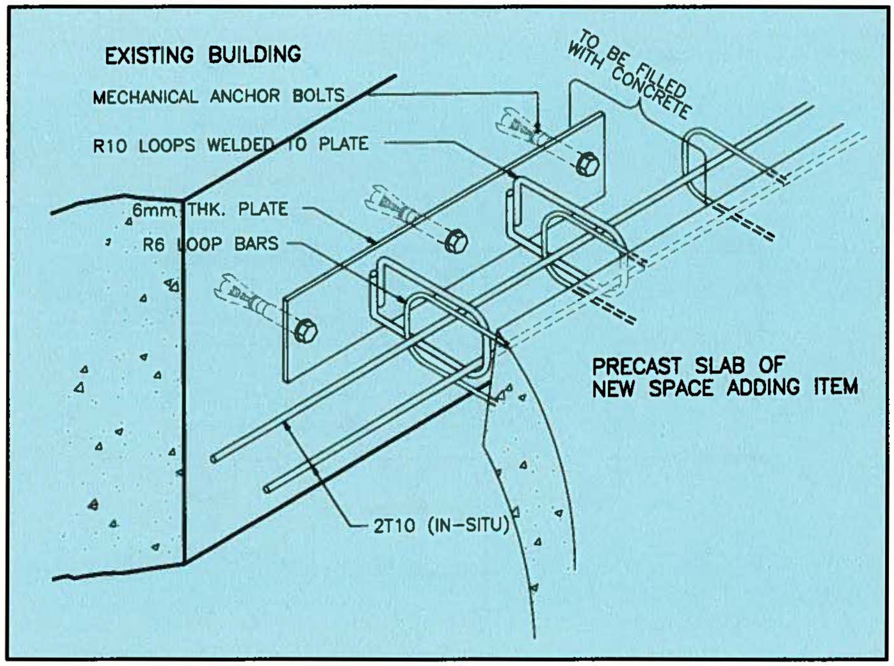


Fig. 5. Horizontal tie connector plate detail.

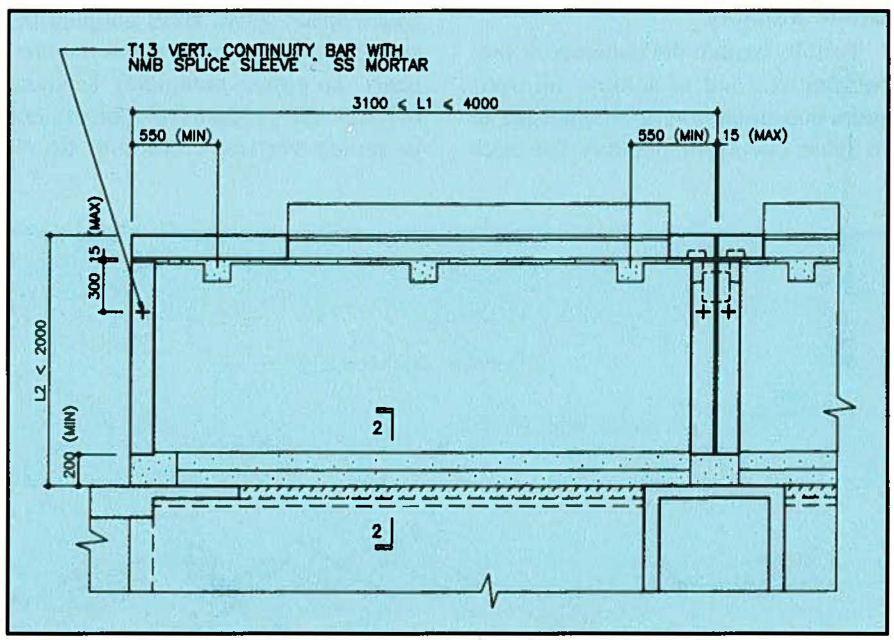


Fig. 6. Typical story floor plan and section of added space.

ADDED SPACE DESIGN CONCEPTS

In carrying out the upgrading program, several innovative concepts were applied to the building elements:

Foundation

The new added space stack is designed to be completely supported on new independent foundations. Because of the stringent noise and dust regulations, pilings for these new foundations can only be done by jack-in or boring methods. Very often, the design and construction of these new foundations is complicated by obstructions from existing building pilecaps and footings or by underground sewage, gas or water main lines.

Where possible, sewer lines are diverted before piling work commences. If this cannot be done, the piling as well as the corresponding pilecaps have to accommodate these services, which may result in an elaborate configuration of ground transfer beams, as illustrated in Figs. 2 and 3.

Piling Types

A summary of the various piling systems used for the foundations of the added space is illustrated in Table 2. Jack-in and micropiling systems are the most extensively used systems with a cost range of $3.50 to $4.00 per meter tonne (in Singapore dollars).

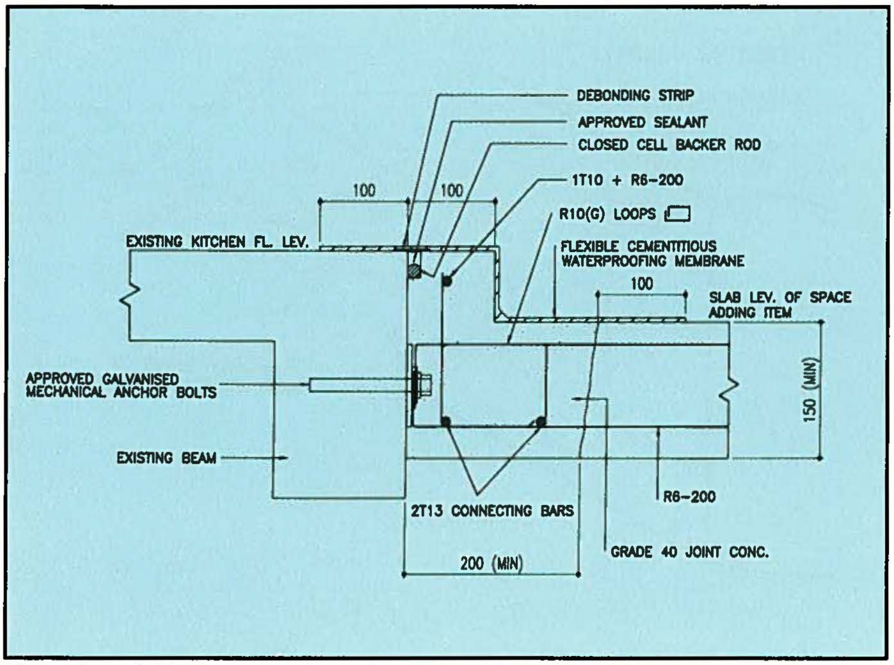


Fig. 6. (cont.). Typical story floor plan and section of added space.

Stack Stability

To fully exploit the potential of prefabrication, and to achieve an optimum construction turn-around time of at least one floor per day for each added space stack, HDB adopted the use of large precast concrete components. To ensure monolithic behavior between the precast components and to satisfy vertical continuity tie requirements, 13 or 16 mm (1/2 or 5/8 in.) diameter, high tensile bars are embedded in the walls and spliced together with the proprietary NMB splice system, as shown in Fig. 4.

The added space stack may vary from 4 to 25 stories depending on the existing building height. Lateral stability is achieved by tying the ends of the precast slabs to the edge beams of the existing building (see Fig. 4). A hot dipped galvanized steel plate connector bolted down to the peripheral beams with mechanical bolts is used (see Fig. 5). A minimum of two tie plates per floor is recommended. Each tie plate has been designed to withstand a maximum pull-out force not in excess of 0.5 tons (0.45 t).

Designing for Existing Building Tolerances

Many existing apartments have inherent building workmanship alignment problems. In added space designs these problems are accommodated by specifying a 200 mm (7.8 in.) stand-off distance between the face of

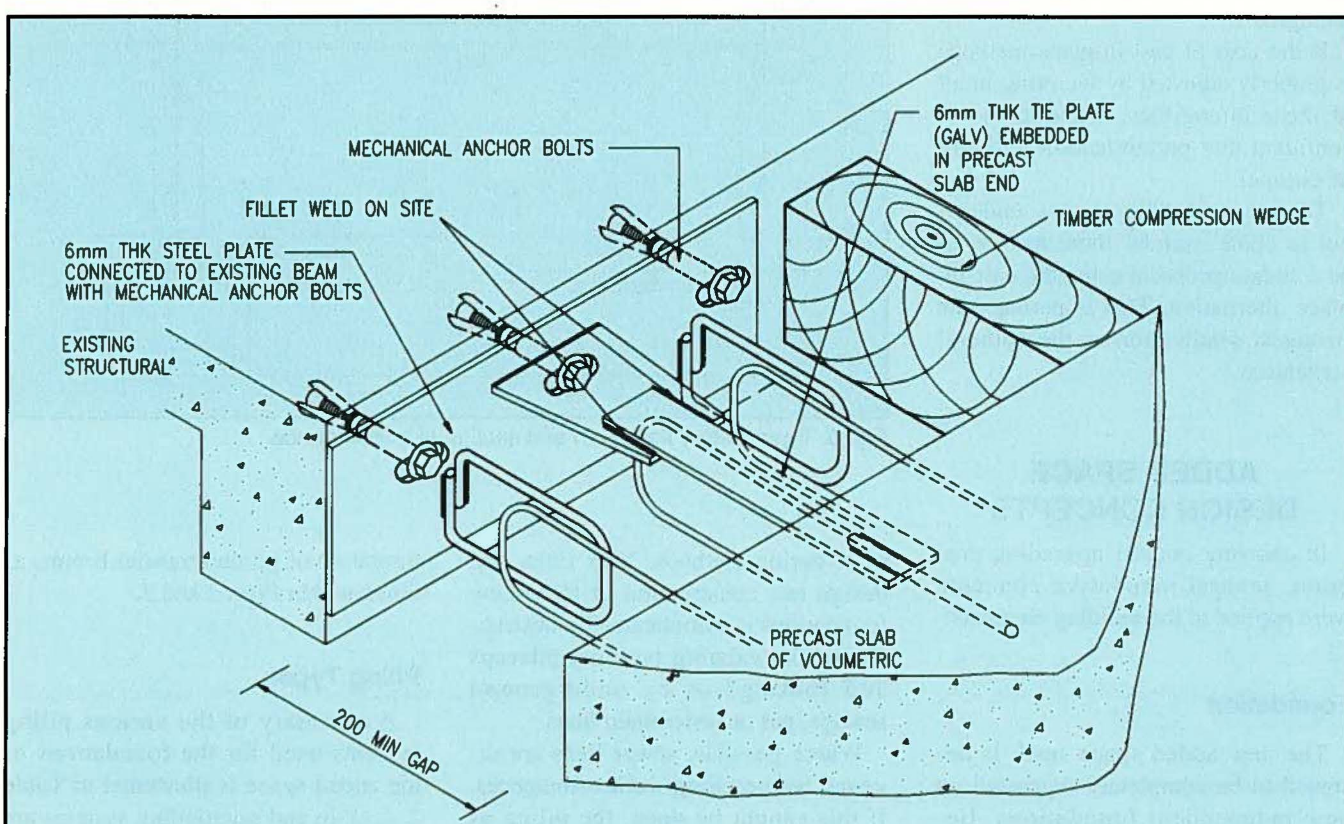


Fig. 7. Tie connector between precast concrete added space slab end and existing building peripheral beam modified for temporary structural bracing.

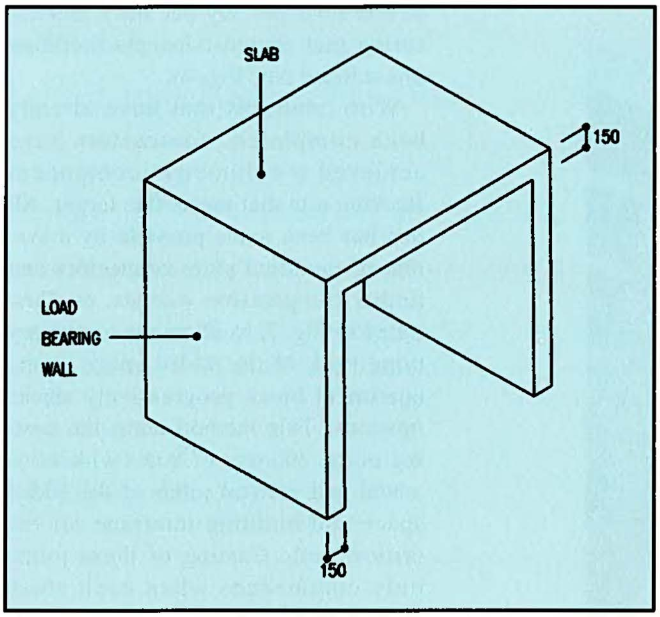


Fig. 8. System 1 basic N Volumetric consisting of two walls with linking slab element.

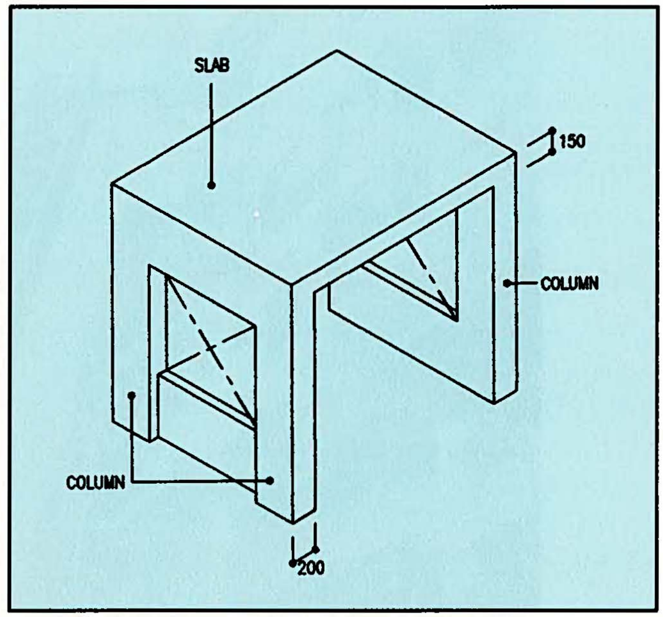


Fig. 9. System 1 modified N Volumetric consisting of two column frames with linking slab elements.

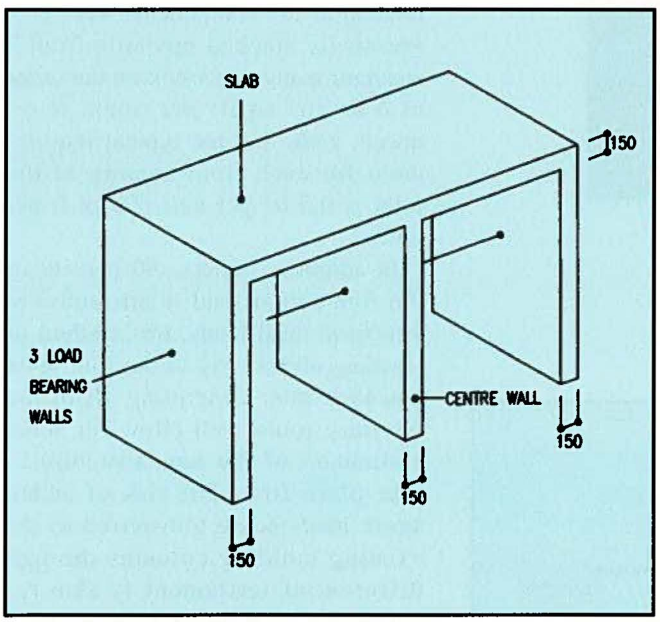


Fig. 10. System 2 basic M Volumetric consisting of three walls with linking slab element.

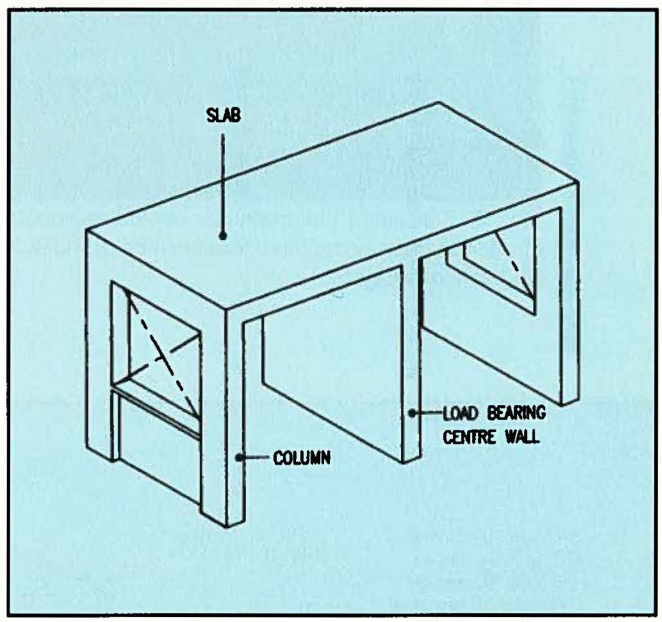


Fig. 11. System 2 modified M Volumetric consisting of two column frames and one center partition wall with linking slab element.

the existing building and the edge of the precast elements. This gap, which will be filled with joint concrete at a later stage, not only facilitates the erection of the precast components but also allows the installation of the connecting bars (locking pins) for the tie plates.

In addition to this, an 80 mm (3 in.) drop between the existing building and the structural finished floor level of the SAI will accommodate floor-to-floor height variances within the building (see Fig. 6).

Cost Effective Designs for Volumetrics

The precast volumetric concept for the added space will only be viable if the following points have been incorporated into the design:

1. Depending on existing site accessibility and the type of cranage to be used, for high rise apartment blocks up to 16 stories in height [assuming 2.7 m (8.8 ft) per story], the weight of the volumetric should on average be kept to 10 tons (9 t). A mixture of mobile/crawler or tower cranes may be used, the final decision being dictated by site and cost factors. For point apartment blocks up to 25 stories, tower cranes are the main lifting device. To keep the cost of cranage low, the weight of the components must be kept below 6 tons (5.4 t) each.

2. The precast system must yield an optimal construction turn-around time. HDB approached this issue by specifying a minimum floor erection speed

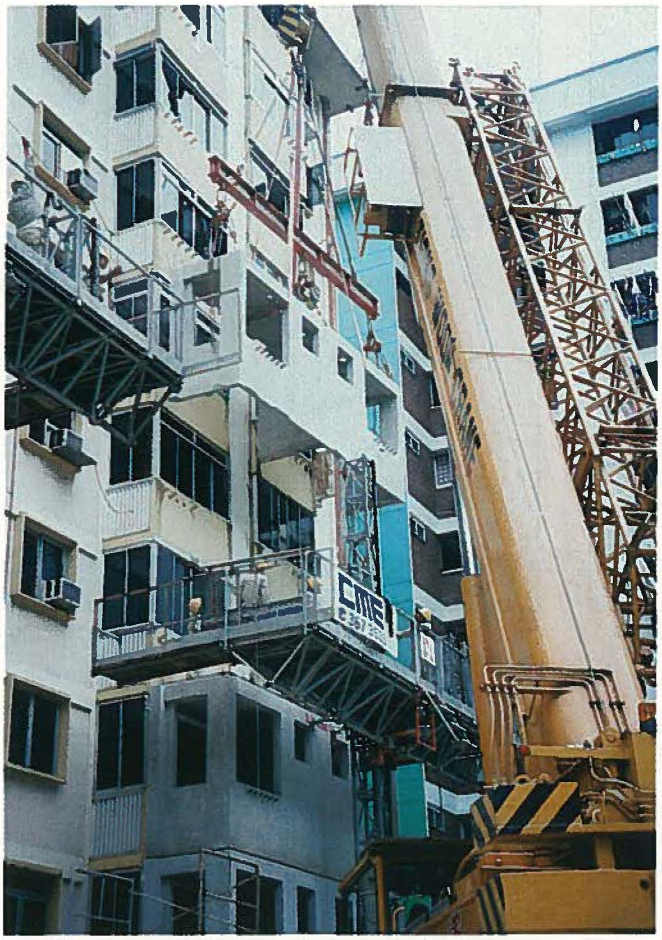


Fig. 12. Precast M Volumetric for two combined units of added space being lifted into position at Block 32 St. Michael's Estate.

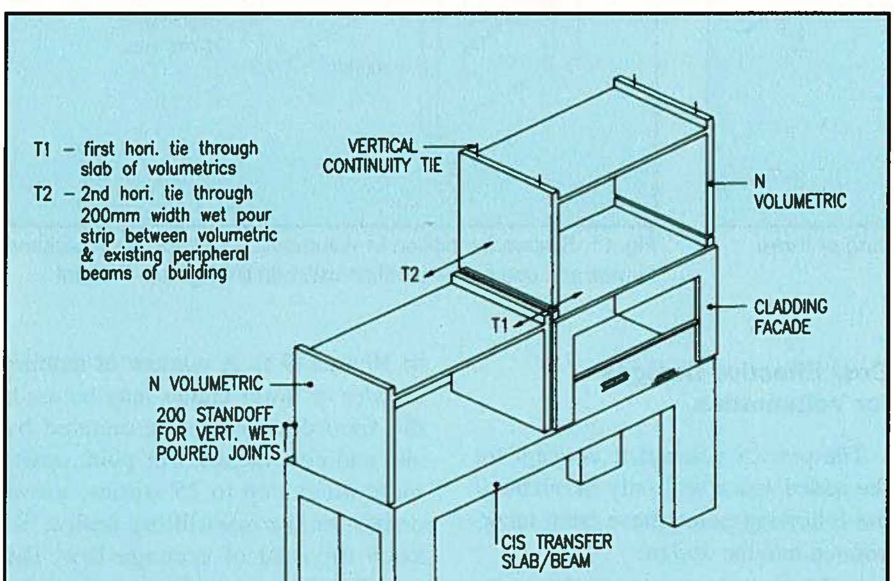


Fig. 13. System 3 — Two adjacent N volumetrics stacked together and supported on common transfer beam at second story.

of one floor per day per stack and ensuring that design concepts facilitate this scheme (see Fig. 4).

With contracts that have already been completed, contractors have achieved a volumetric component stacking rate that meets this target. All this has been made possible by a system of modified plate connectors and timber compression wedges, as illustrated in Fig. 7, to allow the temporary tying back of the added space as the apartment block progressively stacks upwards. This method takes the casting of the 200 mm (7.8 in.) wide horizontal and vertical joints at the added space and building interface off the critical path. Casting of these joints only commences when each stack reaches roof level.

Concrete waste, which would have been very high if the contractor had attempted a floor-by-floor casting method as the components were progressively stacked upwards from a standard ready mix truck on the order of 6 m^2 (65 sq ft) per truck, is reduced. Note that the typical requirement for each floor casting of the joint is 0.5 m^3 per unit (18 cu ft per unit).

In addition, because 90 percent of the foundation load is attributed to structural dead loads, this method of stacking all the way to the roof level and then later concreting all of the interface joints will allow for some settlement of the new structure to take place first. The risk of added space loads being transferred to the existing building columns through differential settlement is also reduced, not to mention a corresponding reduction in the development of major cracks at the building-SAI interface. To date, nine blocks of high rise apartment blocks in Marine Parade Estate, ranging from 14 to 25 stories, have been successfully upgraded with the added space utilizing this concept.

This estate is underlain with very soft marine clay and the added space stands on steel piles that have been driven to a depth of 44 m (144 ft). More than 2 years have elapsed without any visible sign of cracking due to differential settlement at the new and old building interface.

Fig. 14. Precast volumetric (N type) stack supported on transfer beam at second story.

Fig. 15. Work platform and precast volumetric stacking system combination improves erection speed.

VOLUMETRIC STACK SYSTEMS

The several stack systems that have been developed revolve around a precast concrete facade or parapet component bolted or cast monolithically with the core element termed the N or M Volumetric.

By varying the facade shape, and modifying the column frame/wall configurations, the architect has the flexibility to achieve many variations in balcony stack designs.

Single Stack System

The core element here is configured around two support walls 150 mm (6 in.) thick with a 125 or 150 mm (5 or 6 in.) linking slab element (see Fig. 8). Alternatively, the slab rests on a column frame system (see Fig. 9). To minimize the number of construction steps, it is customary, with the weight permitting, for the facade to be cast monolithically with the core body.

This system has been used extensively for the construction of single stack new private balconies, service yards and utility rooms in many upgrading projects. The overall concept is best explained through the schematics and photographs showing the additional space construction works for the pilot project at Block 24 of Teban Gardens (see Fig. 1).

Twin Stack (System 2)

This system uses a core element called the M Volumetric configured around a 125 or 150 mm (5 or 6 in.) thick slab element resting on three walls (see Fig. 10) or two column frames and a center partition wall (see Fig. 11).

This system is preferred when two single stacks are built adjacent to each other and only if the total component weight can be kept under 10 tons (9 t) (see Fig. 12).

Twin Stack

Upgrading construction is usually executed in heavily built-up areas with many existing site constraints that will inhibit the use of heavy capacity cranage for lifting. This system was specifically developed to work around this problem by breaking up the heavier M Volumetric into two N Volumetric components supported on a transfer beam located at the second story (see Fig. 13). This format has found wide application in the construction of new service balconies.

With the faster pace of erection, access by workers to all levels of the rising stack is achieved through mobile work platforms. During the whole construction process, workers are not allowed to enter the resident's apartment to work on the added space. However, when each stack is progressively completed, a fixed number of uniformed workers, not exceeding four at any time, are allowed to enter the unit to demolish the reinforced

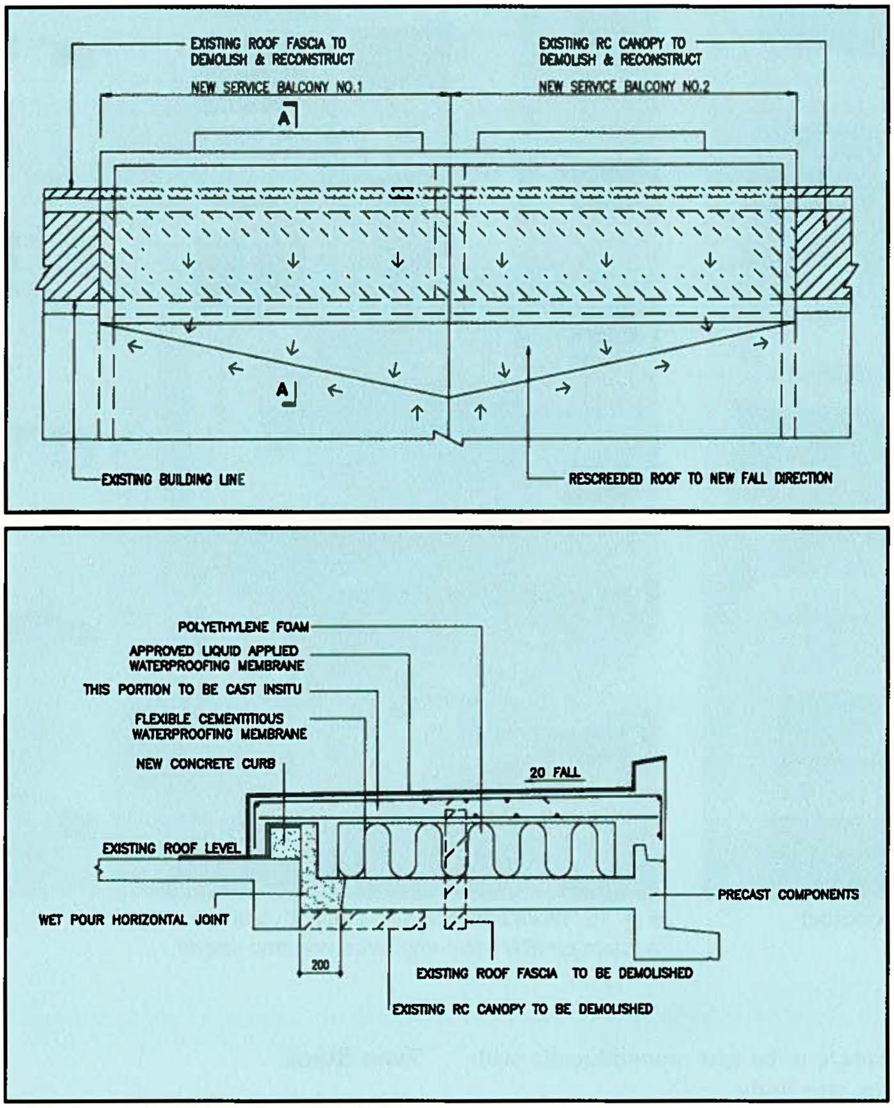


Fig. 16. Roof plan and section illustrating the interfacing of new twin added space structure with existing building roof.

concrete or masonry walls to link the existing apartment to the new added space. They must complete their work and vacate the affected apartment within 14 days.

In terms of productivity, a team of six workers, including the crane operator, is normally required instead of 12 workers. For the projects illustrated in Figs. 14 and 15, the added space stack was completed in 16 working days from the time that the second story component was first launched. The authors estimate that this is about three times faster than conventional cast-in-place concrete methods.

DESIGN AT ROOF LEVEL

The roof of the added space is normally crowned off with an architectural feature that is usually prefabricated. As far as the watertightness of the roof is concerned, rainwater runoff is never allowed to flow directly across the horizontal interface joint between the added space stack and the existing building. A precast concrete secondary roof slab, which is integrated with the roof architectural feature (see Fig. 16), drains rainwater over the joint on the existing building roof slab, which is also rescreeded to the new correct fall.

CONCLUDING REMARKS

Prefabrication technology in the form of precast concrete volumetrics is an effective way of constructing additional space to existing high rise apartment blocks for the Public Housing Upgrading Program in Singapore. This fits ideally with HDB's priority of reducing Singapore's dependence on foreign labor and technology through increased construction productivity.

Given the many technical and social constraints of operating in a highly built-up environment, prefabrication has also improved the efficiency and cost effectiveness, and has enhanced the buildability of the additional space extensions to existing apartment units. Importantly, this has been done without compromising either the quality of construction or the finishing workmanship, while at the same time minimizing any disruption to the living conditions of the residents.

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