I. Abstract

In year 2002, HARF (the Housing Authority Research Fund) was set up to support research initiatives related to Housing Department’s operations and objectives. Innovative precast systems are one of the topics of HARF. The areas of study include the use of lightweight aggregate concrete. This paper describes concisely the Housing’s experience in the use of precast panel walls, their performance requirements, advantages and the way ahead; and the possible directions in the application of precast lightweight concrete, its merits, demerits and various considerations.

II. Introduction

As Housing Department oversees the construction of a large quantity of buildings and at the same time manages numerous rental estates, it has particular concern for the time, cost and quality of construction materials used. It thus is placed in a unique position in the promotion of building technology. Since 1990, the Department has adopted prefabricated concrete elements such as facades, staircases as well as panel wall partitions in Housing projects. Recently, a project in Kwai Chung is chosen as the pilot project for a large scale precast system with 65% of the concrete elements precast.

In year 2002, HARF (the Housing Authority Research Fund) was set up to support research initiatives related to HD’s operations and objectives. Innovative precast systems are one of the topics of HARF. The areas of study include the use of lightweight aggregate concrete. The progress so far has been satisfactory and this paper reports some of the findings only. The study is not intended to give a prescription for the use of any precast lightweight systems. The outcome should instead be flexible and dynamic, the industry will be encouraged to develop and take the systems forward.

The paper describes concisely the use of precast lightweight systems:

1) Housing’s experience in the use of precast panel walls, their performance requirements, advantages and the way ahead; and

2) The possible directions in the application of precast lightweight concrete, its merits, demerits and various considerations.
III.  Precast Panel Walls Systems in Housing Department

1. From Brickwork to Drywalls

Before the 1990's, the Department constructed partition walls of kitchens, bathrooms and bedrooms of public housing flats in brickwork or block work (Figure 1 shows a March 1985 version of the Trident Block). At that time, the construction of these partitions involved a large number of labourers and the site conditions were messy and dirty.

The Department recognized the opportunity to use drywalls to reduce wet trades on site and to achieve a higher standard of substrate for subsequent finishing work. Commencing from mid 1990, all Harmony Blocks use drywall partitioning systems in domestic flats in lieu of traditional brick/block work.

The panel walls proposed for public housing contracts must satisfy a set of performance specifications. The panel wall systems thus supplied have successfully evolved through these years to become more matured systems and are generally able to fence off defects such as cracks and water seepage.

Figure 1: Part Plan of Trident Block

75mm blockwall with 15mm plaster on both faces
2. The Requirements

The Panel walls are proprietary systems which should be compatible with the building structure. Their nominal length is specified to be 600mm and has to be lightweight for manual operation on site. The thickness of panel wall should be 85mm minimum because of the need to incorporate electrical conduits of 20mm diameter with at least 30mm cover to prevent penetration of conduits by nails or screws likely to be installed by the residents. The performance requirements are given below:

1) Strength and Robustness

(a) Material Strength

Characteristic strength is established in the precast factories from 100 no. of 150mm concrete cube cast in 3 different casting days. Cube strength is determined statistically from the 28 days strength values with not less than 5% failures.

During production, test cubes are made per every 100m$^3$ or on each casting date to monitor the quality continuously. If there is any noncompliance in strength requirements, the batch of panel walls will be subjected to door slam test as described in the following. If the samples fail to comply with the test requirements, the corresponding batches are to be removed from site.

(b) Performance Test to BS5234

The following tests are carried out to check the level of performance of the walls:

(i) Stiffness
When subjected to an applied load of 500N, the maximum deflection of the panel walls is not less than 15mm and there should be no damage or loosening of the panels. The test is to establish the ability to withstand persons or ladders leaning against them.

(ii) Impact Tests
Both hard body and soft body impact are carried out to check the deformation, indentation and damages of the panel walls. The indentation on wall surfaces is not more than 1.5mm.

(iii) Door Slamming Test
An assembly of panel walls is subjected to impacts of the door leaf weighting not less than 60kg. There should be no visible damage after 100 impacts and the maximum displacement is less than 1mm. It simulates the real situation when the doors adjacent to the panel walls are subjected to repeated opening and forceful closing by occupants.

(iv) Crowd Pressure
When tested with a load of 2kN/m simulating a crowd thrusting against the wall, there shall be no collapse or damage that would render the
(v) Anchorage – Wall Cupboard
Panel walls are used in the kitchens. The test verifies whether the panel wall system can safely support high level cupboards (Figure 2). A load 3kN/m is applied through a bracket anchored to the panel walls subjecting to the test without releasing the pull-up shim plate, exceeding the deformation limit or loosening/damaging the partition.

2) Fire Resistance

The 85mm panel walls used at kitchens have to withstand a FRP of 1 hour. A panel wall system undergoing fire resistance test is shown in Figure 3. Figure 4 shows that the wall under intense fire was found detached from the test frame.

3) Watertightness

There should be no penetration of water when the wall panels are sprayed for at least 2 minutes by a 13mm diameter pipe under a water pressure between 210-240kPa.

4) Compatibility with Tile Adhesive

Panel walls should be able to support wall tiles. In this test, tiles are applied to panel walls using approved adhesive. Pull off tests are carried out by pulling a dolly attached onto the surface of the tiles which have been fixed onto panel walls. The measured tensile stress should not be less than 0.3N/mm².

5) Anchor Test

Special anchors are used to attach fixtures to panel walls. The recommended anchor types for attaching normal fixtures to the panel walls are shown in the
wall manufacturers’ manuals. This is a verification of design proposal of the wall manufacturers.

6) **Sound Insulation**

The weighted sound reduction for the panel walls should be greater than 32dB. Usually, nearly all the panel wall system can easily achieve the minimum requirements. Many systems even exceed 40dB. If the walls are used as internal partitions, sound insulating property may not be considered a very important factor.

### 3. Typical Examples of Panel Walls and Generalized Properties

<table>
<thead>
<tr>
<th>Brand</th>
<th>Y</th>
<th>E</th>
<th>B</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items</td>
<td>85 mm</td>
<td>85 mm</td>
<td>85 mm</td>
<td>85 mm</td>
</tr>
<tr>
<td><strong>Sections of Standard Panel</strong></td>
<td><img src="image1.png" alt="Graphic Rep. of Casting Process" /></td>
<td><img src="image2.png" alt="Graphic Rep. of Casting Process" /></td>
<td><img src="image3.png" alt="Graphic Rep. of Casting Process" /></td>
<td><img src="image4.png" alt="Graphic Rep. of Casting Process" /></td>
</tr>
<tr>
<td><strong>Constituent Materials</strong></td>
<td>Cement + Sand + PFA + Foaming Agent</td>
<td>Cement + Leca + Foaming Agent</td>
<td>Cement + Aggregate + Foaming Agent</td>
<td>Cement + Pearlite + Entraining Additive</td>
</tr>
<tr>
<td><strong>Graphic Rep. of Casting Process</strong></td>
<td><img src="image1.png" alt="Graphic Rep. of Casting Process" /></td>
<td><img src="image2.png" alt="Graphic Rep. of Casting Process" /></td>
<td><img src="image3.png" alt="Graphic Rep. of Casting Process" /></td>
<td><img src="image4.png" alt="Graphic Rep. of Casting Process" /></td>
</tr>
<tr>
<td><strong>Reinforcement</strong></td>
<td>∅4mm mesh coated with Bitumen paint</td>
<td>∅4mm Mild Steel Bar</td>
<td>∅4mm Gal. M.S. Bar</td>
<td>∅4mm Gal. M.S. Bar</td>
</tr>
<tr>
<td><strong>Fixing Method</strong></td>
<td>Fixing Lug</td>
<td>Screw Bolt</td>
<td>Plastic Pad</td>
<td>Screw Bolt</td>
</tr>
<tr>
<td>Items</td>
<td>Brand</td>
<td>Y</td>
<td>E</td>
<td>B</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>Density</td>
<td></td>
<td>550 kg/m³</td>
<td>1200 kg/m³</td>
<td>1100 kg/m³</td>
</tr>
<tr>
<td>Characteristic Strength</td>
<td></td>
<td>3.7 MPa</td>
<td>13.7 MPa</td>
<td>17.39 MPa</td>
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<tr>
<td>Sound Insulation (Reduction)</td>
<td></td>
<td>36 dB</td>
<td>42 dB</td>
<td>42 dB</td>
</tr>
<tr>
<td>Hardness (Indentation)</td>
<td></td>
<td>1.4 mm</td>
<td>0.6 mm</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>Fire Resistance</td>
<td></td>
<td>&gt; 200 minutes</td>
<td>&gt; 120 minutes</td>
<td>&gt; 65 minutes</td>
</tr>
</tbody>
</table>

4. The advantages

Precast Panel wall partitions have major advantages over conventional partition walls in aspects of efficiency in construction, environment friendliness and cost. They are elaborated below:

1) Time

Instead of assembling a large number of blocks one by one, each panel wall of size 600mm x 2500mm can be installed in one go. Construction of panel wall is obviously more efficient than masonry walls. Because of high degree of surface flatness, only a skim coat which is quick to apply is required on panel walls. The time for finishing work is much shortened. According to some panel wall suppliers, the construction cycle per floor is about 5 times quicker than masonry walls. Pre-installation of conduits in panel walls also saves building services work on site and facilitates early completion of the projects.

2) Cleanliness

Panel walls are manufactured in factories and delivered to site in various sizes for assembling on site. Because the walls can be manufactured accurately to size and shape and the plastering incurred is just minimal, many wet trades such as plastering can be significantly reduced, resulting in big enhancement of site cleanliness.

3) Spacious Interior
The overall thickness of panel walls is smaller than that of block work due to the absence of thick plastering. This results in more livable space inside the flats.

4) Environment

The reduced wet trades and wastage on site help achieve environmental objectives. For the reason that conduits are preinstalled in the panel walls in factories, chiseling and cutting on site to accommodate the electrical conduits and sockets, which create a lot of noise, dust and waste, is not necessary.

5) Cost

The cost of panel walls is quite competitive in comparison with masonry walls. Even for some expensive proprietary panel wall systems, the more expensive material costs can be offset by the reduction in plastering work.

The panel walls are light weight. They are appreciably lighter than brickwork or block work. Hence there will be less weight of wall materials and plastering to be transported. With additional savings on transportation cost, cleansing work, reduced wastage and higher efficiency of installation, the costs of panel walls would be lower than other types of walls. If extra usable area is accounted for, the saving is quite attractive.

Depending on the amount of panel walls used in a building, their light weight property can reduce the loading on structural members such as slabs, walls as well as the overall load on the foundation. This enables further cost savings.

6) Better finished surface

The quality of finished surfaces of panel walls surpasses those of block work or brickwork. A high degree of accuracy and flatness is achievable under factory conditions. The appearance is less dependent on the workmanship of the workmen on site. Panel walls are thus preferred over brick walls or block walls in forming partitions.

5. Attention to Details

Panel walls have definite advantages over conventional walls. Nevertheless, it is important to appreciate their weaker areas in order to seek improvement to the system. From the experience gained from the application to Housing blocks, the areas deserving proper attention are as follows.

As a result of the lightweight materials used and the presence of voids inside panel walls, special fixing screws are used for the attachment of shelves and cabinets (Figure 5). The panel wall suppliers have tested various types of fixing screws suitable to their wall and given recommendations in the manuals. Unlike concrete walls, fixing by ordinary nails or screws may not be satisfactory and specified anchors
should be used for relatively heavy fixtures. The presence of large voids in walls may entail the use of screws that would anchor against the edge of voids as illustrated in Figure 6.

1) **Fixing components to walls**

![](image1)

![Figure 6: Action of Fixing Screw](image2)

2) **Formation of cracks**

Panel walls are usually brittle materials of standard size 600mm with no mechanical connection between panels. Cracks could form in the vertical joints and the interface between panels and ceiling. Each supplier should have their own system of jointing to ensure no cracking at panel interface. The measures include installing fibre mesh at the joints between walls and applying nonshrink cement mortar to completely fill up the joints. Right angle wall joints should be connected by nails of adequate length. Special attention should be paid to the connection between panel walls and concrete walls, particularly structural walls, where cracks could occur in the joints which are not properly formed.

Sometimes potential cracks are aggravated by the deflection of concrete slabs. If the deflection of concrete slabs is excessive, cracks will be induced in the panel walls which deform with the slabs they are resting on. It is always desirable to cater for the normal slab deflections in the design of the panel walls and joint details.

3) **Watertightness**

Because of the use of foaming agent or porous lightweight aggregates, panel walls are more prone to water leakage than concrete walls. Panel walls, similar to other walls, should not be relied upon to stop the passage of water. In washrooms where the walls may be in contact with water, the
employment of an effective waterproofing membrane is necessary. Even in other areas where there would normally be no water, the application of appropriate moisture sealers is a good practice to reduce the likelihood of water leakage through the panel walls. The suppliers should propose acceptable systems to ensure watertightness. As a general guide, sealants should be applied to the joints around shower areas in washrooms and all joints should be completely filled up with non-shrink cement mortar. Workmanship of the workers in the latter operation is particularly important.

4) **Hoisting**

![Figure 7: Crack in wall](image1)

![Figure 8: Hoisting panel walls on site](image2)

In general, the panel walls are relatively weak in strength and are lightly reinforced. If the walls are not properly handled, cracks may manifest after the walls are transported to the floors in the buildings (Figure 7). Most suppliers state in their manuals the recommended ways to handle the walls. It is necessary to check that the contractors understand and act accordingly. A typical method used on site is shown in Figure 8 – please note the wooden planking at the bottom and the method of hoisting, whereas Figure 9 shows an incorrect method of hoisting on site which may cause cracks in the panels.

6. **Recent Developments**

The panel wall system has been developed for more than a decade. Recent developments relating to panel wall system are:
1) Pre-installed electrical conduits and sockets

Taking advantage of the manufacture in factories, electrical PVC conduits and socket boxes are incorporated since 2002 into the panel walls in Harmony projects without much difficulty (Figure 10 & 11). A high degree of accuracy is achievable; the conduits can be positioned within the walls at a nominal cover of 30mm.

The practice saves much trouble on site to saw cut grooves for sockets and conduits and subsequently fill them up with cement mortar, resulting in savings in both costs and time.

2) Minimum Pull-off Strength

Previously, there were no specific strength requirements for panel walls; the contractor is only required to procure a panel wall system satisfying the performance specifications. In Year 2004 Edition of the Housing Specification, the pull-off strength of panel walls is specified to be a minimum of 0.3MPa. This requirement is being further reviewed in light of the enhanced requirement on adhesive strength of tile adhesives.

3) Building Materials Database

In the past, Housing Authority contracts prescribed the use of listed brands and suppliers, i.e. Control Lists, for the specified building materials. The admission into the Control Lists requires satisfying relevant quality standard and admission procedures through a designated team. However, the use of Control Lists may restrict the number of players in the field and could be seen as unnecessarily regulating the market which has become more matured. Decisions were thus made that commencing this year; contracts tendered out do not have to make reference to any material lists. Only a data base of building materials recording the performance of building materials used is kept for internal reference. Any building materials satisfying the specification requirements may be accepted in projects, the project teams are vested with the full responsibility to control the quality of materials they approve. In this way, it is hoped that the building materials
in Housing projects are open completely to market force and more panel wall systems will be in use.

IV Precast Panel Wall Systems in Private Sector

With Housing Department taking the lead in 1990 to drastically change the way internal partition walls is built, the private sector has begun to turn the focus on the use of precast panel walls. Other than domestic buildings, panel walls find increasing use in hotels, hostels and schools in light of their lightness, flexibility, simple and easy-to-install characteristics.

Some years ago, Housing Authority was the major consumer of panel walls – over 95% of the panel walls were supplied to Housing sites in year 2000. Nowadays, the market share according to a recent survey has shrunk to about 30% due to a reduction in Housing production and an increase in use in the private sector. Many panel wall suppliers derive their businesses from private developments which begin to appreciate the high quality, efficiency, cost effectiveness and the beauty of clean and tidy sites.

The use of panel walls is expected to gain popular support as the environmental awareness of the society is raised and more and more people become familiar with the systems. Panel walls are not without their weaknesses, but with more effort and attention to their development, the systems are expected to gain wider acceptance in the construction industry.

V Options of Innovative Precast Systems of Structural Lightweight Concrete

Precast systems using structural lightweight concrete have several potential advantages over normal weight concrete, including:-

- reduced dead load of the structure offers a reduction in foundation size
- smaller lifting equipments for placing precast panels
- floor slabs requiring smaller supporting systems
- lower density, making it particularly suitable with large pour area
- high thermal insulation for buildings
- inherent fire resistance
- reduced construction cost due to time saving and flexibility of design

Considering the factors of buildability and cost, the following options using structural lightweight concrete offer the alternatives to existing Housing Harmony block projects.

(i) Precast composite slab
(ii) Precast staircase with flight & shaft
(iii) Post-tensioning water tank
(iv) Alternative precast façade

i). Precast Composite Slab

The floor slab acts compositely with the precast and in-situ floor slab with an overall depth of 160mm. When precast is done in Mainland China, the maximum width of the precast panel is limited to 4m due to the height restriction of trucks under the transportation regulations. The slab is supported by the load bearing elements, beams and walls, which run along the building perimeter. Grade 35 concrete is used for both the precast and in-situ concrete topping. The stability is provided by the frame action and core wall action.

Advantages and Practicability
- where foundation costs are necessarily high because of heavy loads and poor ground conditions
- better thermal insulation for structural member exposed to great temperature differential
- larger the area of precast composite panel, the joints of current systems are significantly reduced
- reduced density which offers the most economical use of formwork, transport, cranage and other plants
- consistent properties and good quality control under factory conditions
- greater suitability for concealed conduits
- faster construction over the existing system, thus reducing the construction cycle

ii). Precast Stair Shaft

Merits
- no in-situ concrete work is required in the stair shaft area
- external formwork for stair shaft wall construction is omitted to save time and cost
- no external scaffolding required thus saving in cost and time
- shaft internal wall can be pre-finished and thus elimination of wet-trade works in the shaft area
- external finishes and window can be completed during the construction of the precast shaft
wall formworks in the shaft area are eliminated, saving in cost and time
- clean site, good workmanship and saving in cost and time
- existing precast stair flights can be used

Two precast stair shaft construction can be either (a) Scheme 1 consists of columns and hollow section walls formed by cast-in thin walls or (b) Scheme 2 constructed by skin wall which can be used as lost form for construction of in-situ concrete shear walls.

<table>
<thead>
<tr>
<th>Scheme 1</th>
<th>Scheme 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristics</strong></td>
<td><strong>Characteristics</strong></td>
</tr>
<tr>
<td>- hollow section wall for in-situ concrete infill to reduce the self-weight</td>
<td>- walls enclosing the half landing can be constructed as plain concrete walls</td>
</tr>
<tr>
<td>- columns to support half landing beams and slabs</td>
<td>- skin wall can be used as lost form for construction of in-situ concrete shear walls</td>
</tr>
<tr>
<td>- walls have continuity of reinforcement, can be designed to resist moments</td>
<td>- only internal formwork is required for wall construction</td>
</tr>
<tr>
<td>- formwork not required for wall construction</td>
<td>- part of stair shaft wall cannot be designed to resist moment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Construction Method</strong></th>
<th><strong>Construction Method</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- lowering and fix the precast shaft on floor level, starter bars from the lower precast column to be inserted in the sleeves of upper column</td>
<td>- level work with shims on top of the lower precast shaft walls</td>
</tr>
<tr>
<td>- insert reinforcement cages into the hollow wall section</td>
<td>- positioning of the top precast shaft onto the recess of lower shaft, guide rods on lower shaft wall to be inserted into the left-in sleeves</td>
</tr>
<tr>
<td>- construction of floor structures and hollow wall concrete infill</td>
<td>- dry pack/grouting the joint to complete wall connection</td>
</tr>
<tr>
<td>- grouting to complete column connection</td>
<td>- construction of the in-situ shear walls</td>
</tr>
</tbody>
</table>

iii). Post-tensioning Water Tank

The following options of post-tensioning water tank are considered. Each proposal has its particular advantages. The weight of each section is designed to be less than 6 tonnes to allow for lifting. The dimensions of the post-tensioning water tank are similar to the existing water tank in Harmony block projects.
(a) Circular panel with external tendon  
(b) horizontal rectangular units with external tendon  
(c) vertical panel with external tendon  
(d) vertical panel with internal tendon

Buildability Consideration

- stringent requirement on the post-tensioning techniques for one-end jacking at high working level  
- grouting work between precast units has to be closely monitored to ensure watertight. Additional water proofing plaster may be necessary  
- The waterproofing grout for joints has to be non-toxic, non-shrink grout  
- a considerable degree of standardization of dimensions is required because if the precast units are a ‘one-off’ job they are likely to be expensive  
- adequate bearing and fixing must be provided to the supporting units such as roof slabs and the supporting load bearing walls

iv). Alternative Precast Façade Design

According to the existing design, the length of Façade T1Ar has a span of 4.62m, 3.75m, 2.3m and 2.3m. If lightweight concrete of density 1.85ton/m³ is used instead of normal weight concrete for façade design, the length of the Facade can be extended to about 6m. Table 1 below shows the different extensions achieved by using various densities of lightweight concrete.
Table 1: Extended length of façade using LWC

<table>
<thead>
<tr>
<th>Type</th>
<th>Original length of façade (m)</th>
<th>Total wt using NWC (2.4 ton/m³)</th>
<th>Total wt using LWC (1.85 ton/m³)</th>
<th>Extra length (m) of façade by LWC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total wt using NWC (2.4 ton/m³)</td>
<td>Total wt using LWC (1.85 ton/m³)</td>
<td>Density 1900</td>
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<tr>
<td>T1Ar</td>
<td>4.62</td>
<td>1407.758</td>
<td>1085.147</td>
<td>1.191</td>
</tr>
<tr>
<td>T3Ar</td>
<td>3.75</td>
<td>1653.408</td>
<td>1274.502</td>
<td>1.399</td>
</tr>
<tr>
<td>T2Ar</td>
<td>2.3</td>
<td>735.796</td>
<td>567.176</td>
<td>0.623</td>
</tr>
<tr>
<td>T5Ar</td>
<td>2.3</td>
<td>615.352</td>
<td>474.334</td>
<td>0.459</td>
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</tbody>
</table>

Figure 13: Coloured plan showing different precast facades
Merits

Conceptual study on alternative precast facade has indicated that the use of lightweight double storey façade or façade with extended length could reduce the total number of precast components utilized onto the building and contributes to the following advantages:

- weight can be further reduced by 30% if lightweight concrete is used, leaving more flexibility in dimension changes to the architecture
- existing crane system does not change
- giving flexibility to architectural design which may fit to specific site conditions; providing spaces for larger and wider windows for better views and natural ventilation
- allowing larger precast façade for larger flats where normal weight facades are over-weighted when used
- the use of lightweight structures can reduce the foundation load
- by combining two precast components into one, it significantly reduces the totally number of precast components to handle for the entire structure. The reduction in the total quantity of precast components leads to significant reduction in joints and further minimizes the areas of potential water leakage.
- less cast in-situ wet trades and fewer connection joints construction; shorten the installation time and overall construction cycle. less crane usage allows for rescheduling of the existing work program and reallocation of resources. The shortening the construction time and expedite in progress implies cost saving with higher productivity and effectiveness.

Drawbacks

- the concept of double storey façade is feasible only where site precast yard is available. Larger panels also generate storage problem on site.
- double storey façade usually has the height of 5-6m which will generate difficulties in transportation by normal trucks
- stronger temporary bracings and support struts are required to stabilize the double height panel. Accordingly, the floor slab in mid-level has to be voided for the construction of supporting members to the double height façade; extra works are needed to establish and dismantle the support system
• double height façade may generate higher risk of falling during erecting, hoisting and placing due to its larger horizontal wind loads and its practically difficulties for installation works at high level.
• even lightweight concrete is used; some of the double height façade may exceed the loading capacities of the normal tower crane.
• the 2-storey construction method requires rescheduling of the work programme which changes the current practice adapted by the industry.
• the construction joints of the double height façade at alternative floors will be different which may affects the construction cycle.

The only alternative solution by double storey façade approach is to change it into cladding system where only mechanical connection would be required; so that the operation would not be in the critical path.

VI. Cost Analysis of Structural Lightweight Concrete Precast Systems

Example of Cost Analysis Model is shown to analyze the LWC composite slab of 100mm thick precast LWC panel with 60mm in-situ NWC topping. The cost analysis is based on the foundation saving and that further reduction in overall cost is possible when the saving in labour, material handling and shorten schedule etc are included. From Table 2, the weight saving by lightweight (with 1850 Kg/m³ density) composite slab to the foundation load is 5.57%.

Table 2: Example of weight saving by lightweight composite slab on foundation load

<table>
<thead>
<tr>
<th>Element</th>
<th>(m³)/floor</th>
<th>(m³)/floor</th>
<th>floor</th>
<th>(m³)</th>
<th>(m³)</th>
<th>2.40</th>
<th>1.90</th>
<th>1.85</th>
<th>1.80</th>
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<tbody>
<tr>
<td>façade</td>
<td>-</td>
<td>57.01</td>
<td>40.00</td>
<td>-</td>
<td>2,280.40</td>
<td>2,280.40</td>
<td>5,472.96</td>
<td>5,472.96</td>
<td>5,472.96</td>
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<tr>
<td>stair shaft</td>
<td>-</td>
<td>6.01</td>
<td>40.00</td>
<td>-</td>
<td>240.43</td>
<td>240.43</td>
<td>577.03</td>
<td>577.03</td>
<td>577.03</td>
</tr>
<tr>
<td>water tank</td>
<td>-</td>
<td>199.44</td>
<td>1.00</td>
<td>-</td>
<td>199.44</td>
<td>199.44</td>
<td>478.66</td>
<td>478.66</td>
<td>478.66</td>
</tr>
<tr>
<td>slab</td>
<td>44.47</td>
<td>30.43</td>
<td>40.00</td>
<td>1,778.80</td>
<td>1,217.20</td>
<td>2,996.00</td>
<td>7,190.40</td>
<td>6,301.00</td>
<td>6,212.06</td>
</tr>
<tr>
<td>core wall</td>
<td>-</td>
<td>40.01</td>
<td>40.00</td>
<td>-</td>
<td>1,600.40</td>
<td>1,600.40</td>
<td>3,840.96</td>
<td>3,840.96</td>
<td>3,840.96</td>
</tr>
<tr>
<td>wall</td>
<td>-</td>
<td>176.93</td>
<td>40.00</td>
<td>-</td>
<td>7,077.20</td>
<td>7,077.20</td>
<td>16,985.28</td>
<td>17,538.24</td>
<td>17,538.24</td>
</tr>
</tbody>
</table>

Total bldg wt (tonne) 17,560.01

Table of weight saving by lightweight composite slab on foundation load

<table>
<thead>
<tr>
<th>Element</th>
<th>(m³)/floor</th>
<th>(m³)/floor</th>
<th>floor</th>
<th>(m³)</th>
<th>(m³)</th>
<th>2.40</th>
<th>1.90</th>
<th>1.85</th>
<th>1.80</th>
</tr>
</thead>
<tbody>
<tr>
<td>façade</td>
<td>-</td>
<td>57.01</td>
<td>40.00</td>
<td>-</td>
<td>2,280.40</td>
<td>2,280.40</td>
<td>5,472.96</td>
<td>5,472.96</td>
<td>5,472.96</td>
</tr>
<tr>
<td>stair shaft</td>
<td>-</td>
<td>6.01</td>
<td>40.00</td>
<td>-</td>
<td>240.43</td>
<td>240.43</td>
<td>577.03</td>
<td>577.03</td>
<td>577.03</td>
</tr>
<tr>
<td>water tank</td>
<td>-</td>
<td>199.44</td>
<td>1.00</td>
<td>-</td>
<td>199.44</td>
<td>199.44</td>
<td>478.66</td>
<td>478.66</td>
<td>478.66</td>
</tr>
<tr>
<td>slab</td>
<td>44.47</td>
<td>30.43</td>
<td>40.00</td>
<td>1,778.80</td>
<td>1,217.20</td>
<td>2,996.00</td>
<td>7,190.40</td>
<td>6,301.00</td>
<td>6,212.06</td>
</tr>
<tr>
<td>core wall</td>
<td>-</td>
<td>40.01</td>
<td>40.00</td>
<td>-</td>
<td>1,600.40</td>
<td>1,600.40</td>
<td>3,840.96</td>
<td>3,840.96</td>
<td>3,840.96</td>
</tr>
<tr>
<td>wall</td>
<td>-</td>
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<td>17,538.24</td>
<td>17,538.24</td>
</tr>
</tbody>
</table>

Total bldg wt (tonne) 17,560.01

Assumption:
1. all types of wall are in 200mm thick
2. doors at flats are in 0.80 (W) x 2.00 (H) and the main doors are in 1.00 (W) x 2.00 (H)
3. windows near stair shaft are in 0.90 (W) x 0.60 (H)
4. the dimensions are referred to the drawings of New Harmony C Option 6
5. Number of floors is 40

The only alternative solution by double storey façade approach is to change it into cladding system where only mechanical connection would be required; so that the operation would not be in the critical path.
VII. Availability of Lightweight Aggregates

1). North America
   a) Haydite (expanded shale)
   b) Solite (expanded shale) (ASTM C-330, C-331 and AASHTO M195)

2). Europe
   a) Leca (expanded clay), Danish
   b) Lytag (sintered PFA), U.K.
   c) Liapor (expanded clay), Germany

3). Mainland China
   There are various kind of lightwight aggregate available in Mainland China:
   a) Leca (expanded clay), Dongguan (GB2839-81 or BS3797-1990)
   b) Shi aggregate (sintered PFA), Shanghai (GB2839-81)
   c) Guanda aggregate (expanded shale), YichangChina (GB/T 17431.1-1998).

VIII. Constructability Considerations of Structural Lightweight Concrete

1). Production of Lightweight Aggregate Concrete

   Usually lightweight aggregate concrete is cast with a lower slump than normal weight concrete. When properly proportioned, structural lightweight aggregate concrete can be delivered and placed with the same equipment as normal weight concrete. Basic principles required to secure a well placed lightweight aggregate concrete include

   A) Well proportioned, workable mixtures that use a minimum amount of water.
   B) Equipment capable of expeditiously moving concrete.
   C) Proper consolidation in the forms.
   D) Quality workmanship in finishing
2). Quality Control for the Supply of Lightweight Aggregate

In general, the following properties of lightweight aggregates can be specified for the quality control on the supply of lightweight aggregates.

- Particle density
- Bulk density
- Total porosity
- Grading
- Crushing strength
- Absorption characteristics

The effect of absorption water by the lightweight aggregate particles is significant in concrete production. To control the possible slump loss with time during concrete delivery, the absorption can be reduced by pre-wetting the aggregate. A number of methods can be used. They are:

- immerse the aggregates in water.
- continuous water sprinkling of stockpiled aggregate.
- storing the aggregate in a water pool.
- pre-wet the aggregate in the mixer at the beginning of the mixing process.
- vacuum-soaking.

Pre-wetting the aggregate in the mixer is commonly used. It is successful because most of the water absorption takes place during the first few minutes of soaking. The most effective method of pre-wetting is by vacuum-soaking. It can be finished within a short time, but it is expensive. When the vacuum-treated aggregates are stored, they should be continuously sprayed with water to avoid drying out.
3). Design for Structural Lightweight Concrete

BS 8110: Part2: 1985 already provides the guidance notes for the structural design of lightweight aggregate concrete.

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear Resistance</td>
<td>The shear capacity of the concrete cross-section when using lightweight aggregate is taken 0.8 of the value for the equivalent grade of normal weight concrete.</td>
</tr>
<tr>
<td>Deflections</td>
<td>the modulus of elasticity may be obtained by multiplying the appropriate figure for normal weight concrete by ((w/2400)^2), where (w) is the density of the lightweight concrete in kg/m³.</td>
</tr>
<tr>
<td>Anchorage Bond and Laps</td>
<td>Section 5.9 of BS8110: Part 2: 1985, the bond stresses in Section 3.12.8 of BS8110: Part 1: 1985 should not exceed 80% of those calculated for normal weight concrete.</td>
</tr>
<tr>
<td>Concrete Cover</td>
<td>ACI 318 does not differentiate between different concretes when determining the cover requirement; neither does the European code ENV1992. China Standard JGJ 12-99 suggests the cover thickness of distributing bar in slab, wall and shell shall not be less than 10mm.</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>Lightweight aggregate concrete generally displays shrinkage values 20 to 30% greater than normal weight concrete.</td>
</tr>
</tbody>
</table>

**Conclusions**

In this paper, we have described the Housing’s experience in the use of precast panel walls, their performance requirements, advantages and the way ahead; Options and constructability considerations of innovative precast systems using structural lightweight concrete are concluded.

**Acknowledgements**

The research was supported by the Housing Authority Research Fund of Hong Kong Housing Authority.