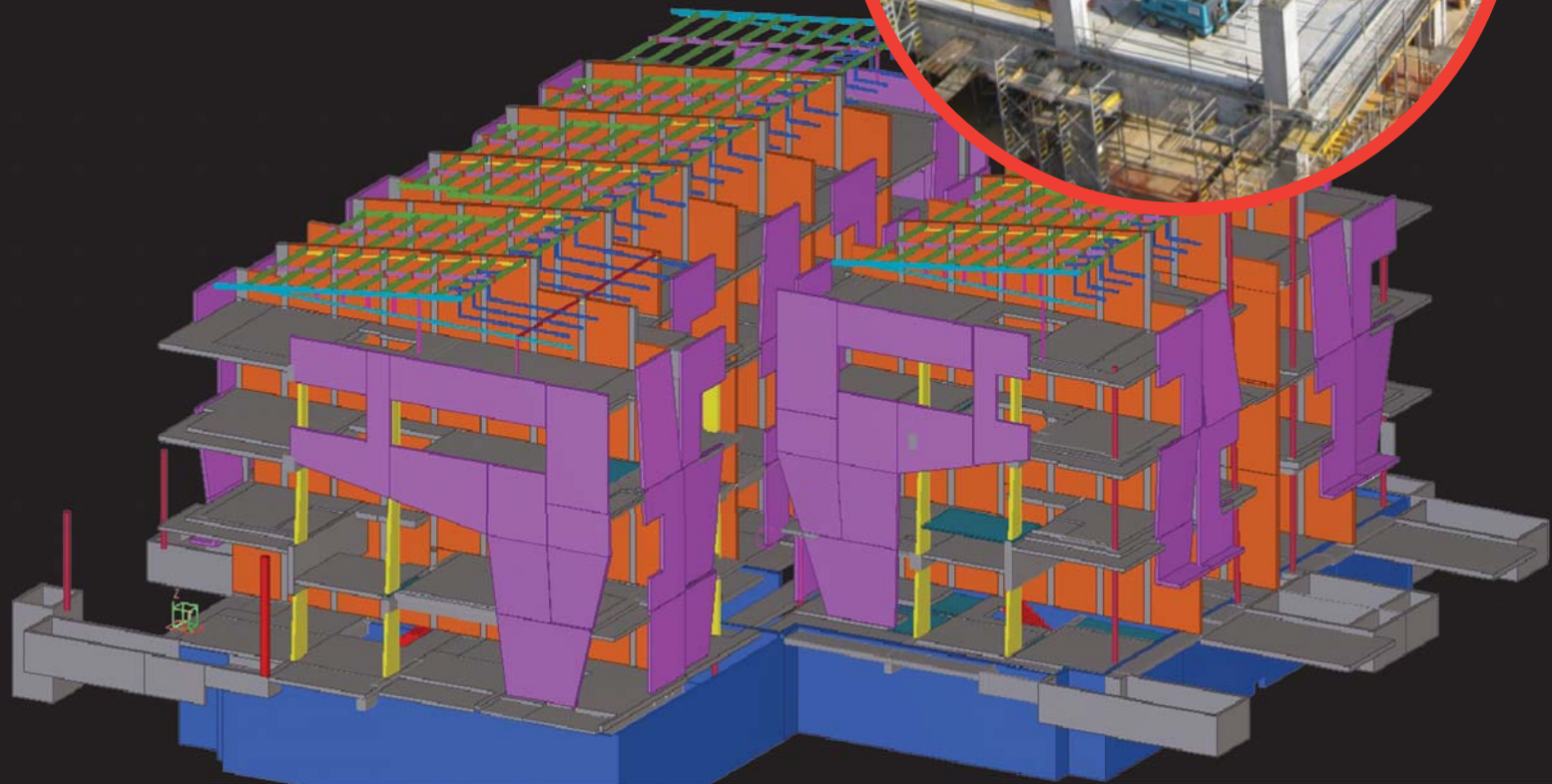


# SUSTAINABLE CONSTRUCTION

A Guide on

# CONCRETE USAGE INDEX

BCA Sustainable Construction Series - 6







# **SUSTAINABLE CONSTRUCTION**

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A Guide on

# **CONCRETE USAGE INDEX**

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As part of BCA's on-going efforts to promote sustainable construction, we have worked closely with key stakeholders from industry and the academia to compile this guidebook, entitled Sustainable Construction - A Guide on Concrete Usage Index (CUI). This is the sixth guidebook on sustainable construction, another demonstration of the collaborative effort between BCA and the industry in shaping a sustainable built environment.

What is CUI? To put it simply, it is an indicator of the amount of concrete used per unit floor area. In Singapore's context, it is a unique way for practitioners to measure and benchmark the amount of concrete used in building works to arrive at an optimal design early in the design and construction process.

In our previous Sustainable Construction publications, emphasis was placed on the downstream process of building construction - codes and usage of alternative building and construction materials such as recycled concrete aggregates. To complement this, we are now focusing on the upstream process of design, which is just as critical in helping us to optimise the use of concrete and other construction materials.

In this publication, some exemplary methods and technologies to achieve low CUI are introduced. In addition, we are also featuring several building projects with good CUI, the teams behind the projects and their insights on how to optimise concrete usage. These case studies and best practices also demonstrate the general alignment between achieving low CUI and initiatives on improving productivity and buildability. They are by no means exhaustive but we hope to inspire industry practitioners to strive for excellence in environmental sustainability by optimising the use of concrete in their building designs.

I am confident that through good design practices and the adoption of appropriate technologies and methodologies, together we will be able to shape a better and more sustainable built environment for future generations.

**DR JOHN KEUNG**  
**Chief Executive Officer**  
**Building and Construction Authority**





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**SECTION 01**

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# **SUSTAINABLE CONSTRUCTION MASTERPLAN**

# SUSTAINABLE CONSTRUCTION (SC) MASTERPLAN

Objective: Savings in Aggregates for Building Works



Fig.1

SUSTAINABLE CONSTRUCTION  
FRAMEWORK

The Sustainable Construction (SC) Masterplan was first formulated in 2007 and subsequently revised in 2009 in line with the goals of the Sustainable Singapore Blueprint, to improve resource efficiency and to achieve zero landfill.

Sustainable development works towards guarantying that the environment and resources are managed to ensure a better quality of life for everyone. This includes setting targets, designing for minimum waste, re-using existing built assets, aiming for lean construction, minimising energy in construction and in use, reducing pollution rates, preserving and enhancing biodiversity, conserving water resources, meanwhile respecting people and their local environment. Sustainable development is mainly about the goal of achieving a balance between environmental protection, social progress, and economic growth. As a part of this movement, the construction industry is expected to enhance and better protect the natural environment, deliver buildings and structures that provide greater satisfaction, and minimise its impact on the consumption of energy.

## OPTIMAL USE OF CONCRETE

In the context of the SC Masterplan, Concrete Usage Index or CUI refers to the optimal use of concrete in building works. Normally a lower CUI value can be achieved for a building when it is designed more efficiently, without compromising on construction safety and productivity.

CUI currently forms part of the SC Score under GM version 4.1. The SC Score is a pre-requisite for higher-tiered GM projects. GM Gold<sup>Plus</sup> and Platinum projects are required to score at least 3 and 5 points respectively under Section 3.1 of GM version 4.1.

Sustainable Construction is an integral part of Singapore's Sustainable Development and BCA champions and leads the industry in this sustainable construction campaign.

Under the SC Masterplan, BCA aims to reduce the use of natural aggregates in concreting works for buildings through the following measures:

- I. Upstream** - by advocating design for optimising usage of concrete therefore optimising the use of building materials and natural resources
- II. Downstream** - by encouraging recycling, upcycling and the use of SC materials

Other supporting initiatives put in place to anchor these measures include the revised SC scoring method under the Green Mark Scheme (GM version 4.1) and the establishment of the Sustainable Construction Capability Development Fund (SC Fund).

While the SC Score aims to encourage the adoption of SC practices, the SC Fund has been established to build up capabilities of key industry stakeholders.

These points can be acquired by either demonstrating optimal use of concrete via design and construction methodologies / technologies (thus contributing to lower CUI), or optimal use of SC materials such as recycled concrete aggregates (RCA), or a combination of both.

Some of the construction methodologies / technologies, structural systems as well as completed projects achieving reasonably low CUI without resorting to using steel, will be introduced in the following chapters of this guidebook.



## UP-CYCLING STRATEGIES Current vs The Future

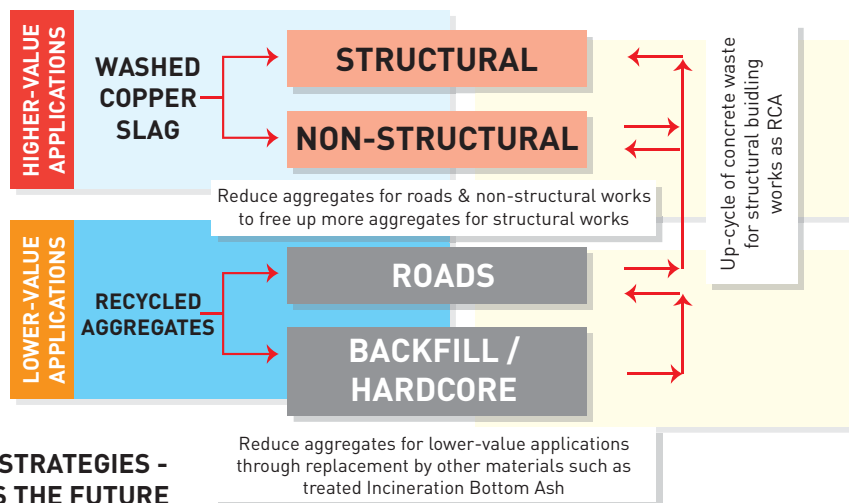


Fig.2

**UPCYCLING STRATEGIES -  
CURRENT VS THE FUTURE**

## RECYCLING, UP-CYCLING AND USE OF SUSTAINABLE CONSTRUCTION MATERIALS

The Semakau Landfill is Singapore's last remaining landfill. BCA aims to reduce waste going to our only remaining landfill by encouraging industry players in construction to recycle, upcycle and to use SC materials in their projects whenever possible. This requires a mindset change of the industry to view every unit of waste as a potential resource during the building and construction process and in the life cycle of the building.

Currently, materials such as concrete waste are still being used for lower value applications like backfilling and construction of temporary site access roads, although studies have shown that they can be put to better use.

Through the SC Masterplan, BCA aims to recycle or 'up-cycle' majority of concrete waste for higher-value applications by processing concrete waste into RCA for structural building works. This concept is illustrated by figure 2, which shows the current status in the blue region, and the future in the yellow region. At the same time, BCA is also exploring the use of other potential waste materials such as treated Incineration Bottom Ash and Dredged Materials in lower value or other civil engineering applications. This would conserve and free up precious natural raw materials like granite for structural building works.

## SUSTAINABLE CONSTRUCTION CAPABILITY DEVELOPMENT FUND (SC FUND)

To build up the capabilities of industry players in adopting Sustainable Construction (SC) practices and technologies, and eventually steer the industry towards self-sustenance in the demand and supply of SC materials in Singapore, BCA established a \$15 million Sustainable Construction Capability Development Fund (SC Fund) in April 2010. The SC Fund is a co-funding scheme that will last for five years or until the \$15 million is fully committed, whichever comes first. It covers up to 50% of the total qualifying cost, depending on the type of application and merits of the project.

The SC Fund focuses on developing capabilities in recycling of waste arising from the demolition of buildings and in the use of recycled materials for construction. The Fund is targeted to assist demolition contractors, recyclers and ready-mixed concrete (RMC) suppliers to adopt appropriate technologies to improve their work processes. On one hand, consistent quality recycled products can be produced and supplied to the end-users like builders, consultants and developers. On the other hand, demand for these products can be sustained since user acceptance is much enhanced with the products compliant to specified industry standards specifications.

The SC Fund was also set up with the intention to encourage more industry players to integrate SC into their designs, construction processes and business operations. Builders, engineers and architects in the building and construction industry not belonging to the three targeted groups above, can also take advantage of the SC Fund to explore, for example, the development of IT tools to facilitate the design of building structures, development of 'green' products and SC technologies, adoption and extensive test-bedding of SC technologies, materials and technical know-how.

Last but not least, the SC Fund supports training and development programmes for the industry. Training providers can tap on the SC Fund to develop and conduct SC-related courses. The Fund can be used to defray costs incurred for development and provision of training materials, contracting the services of trainers, venue rental and the like.

More information on SC Fund can be found at:

**<http://www.bca.gov.sg/Professionals/GovAsst/govasst.html>**





## SECTION 02

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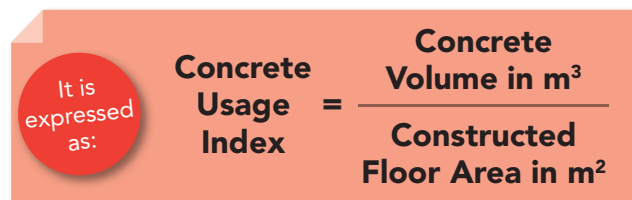
# CONCRETE USAGE INDEX

## CONCRETE USAGE INDEX

### An Introduction

Concrete Usage Index (CUI) is an indicator of the amount of concrete required to construct a superstructure which includes structural and non-structural elements. CUI is defined as volume of concrete in cubic metres to cast a square metre of constructed floor area.

***Calculation of CUI does not include concrete used for external works and sub-structural works such as basements and foundations.***



$$\text{Concrete Usage Index} = \frac{\text{Concrete Volume in m}^3}{\text{Constructed Floor Area in m}^2}$$

## INTRODUCTION TO BCA'S GREEN MARK (GM) SCHEME

BCA Green Mark (GM) is a green building rating system to evaluate a building for its environmental impact and performance. It provides a framework for assessing the overall environmental performance of new and existing buildings to promote sustainable design, construction and operations practices in buildings<sup>1</sup>.

The assessment process involves a pre-assessment briefing to the project team for a better understanding and evaluation of BCA GM requirements and the certification level sought. Actual assessment is then carried out to verify the relevant reports, documentary evidences and that the building project meets the intents of the criteria and certification level.

The assessment identifies the specific energy efficient and environment-friendly features and practices incorporated in the projects. Points are awarded for incorporating environment-friendly features which are better than normal practice. The total number of points obtained provides an indication of the environmental friendliness of the building design and operation.

Depending on the overall assessment and point scoring, the building is certified to have met the BCA GM Platinum, Gold<sup>Plus</sup>, Gold or Certified rating.

The Green Mark Scheme, category Part 3 – “Environmental Protection” focuses on design, practice and selection of materials and resources that would reduce the environmental impact of built structures. Under this category, through part 3.1 – Sustainable Construction, recycling and the adoption of building designs, construction practices and materials that are environmentally friendly and sustainable are encouraged. There is also a pre-requisite requirement to achieve 3 points for Gold<sup>Plus</sup> projects and 5 points for Platinum projects.

Under this sub-category, points can be achieved through use of sustainable and recycled materials or by optimal use of concrete for building components.

## SCORING FOR CUI UNDER GM VERSION 4.1

For new residential and non-residential buildings, points are allocated to encourage optimal use of concrete for building components based on the Concrete Usage Index value achieved, as shown in figure 3.

Documentary evidence is required when scoring for CUI under GM. All documents submitted for the BCA Green Mark Assessment should be duly verified by appropriate practitioners where applicable. These include architectural and structural plan layout, elevation and sectional plans showing the type of wall system used, the dimensions and sizes of all the building and structural elements and calculations showing the quantity of concrete for each floor level<sup>2</sup>.

PROJECT CUI (m <sup>3</sup> /m <sup>2</sup> )	POINTS ALLOCATION
≤ 0.70	1 point
≤ 0.60	2 points
≤ 0.50	3 points
≤ 0.40	4 points
≤ 0.35	5 points

Fig.3

### SCORING UNDER BCA GREEN MARK FOR NEW RESI / NON-RESI BUILDINGS

Encourage designs with optimal usage of concrete for building components.

Prerequisite Requirement :

Minimum points to be scored under this criterion:

Green Mark Gold<sup>Plus</sup> ≥ 3 points

Green Mark Platinum ≥ 5 points

**Remark : One bonus point will be given for the computation of CUI under Part 5-1 "Other Green Feature."**

## WORKED EXAMPLE FOR CUI CALCULATION

LEVEL	CONCRETE USAGE FOR THE SUPERSTRUCTURE (m <sup>3</sup> )			CONSTRUCTED FLOOR AREAS (m <sup>2</sup> )
	BEAM	SLAB	COLUMN	
1 <sup>st</sup> Sty	12.80	37.50	6.25	110.00
2 <sup>nd</sup> Sty	10.50	35.00	5.20	106.00
Typical floor (22 stys) 3 <sup>rd</sup> to 24 <sup>th</sup>	3.6 x 22 = 79.20	32.40 x 22 = 712.80	5.00 x 22 = 110.00	106 x 22 = 2,332.00
Roof level	10.50	35.00	5.20	108.00
Total	113.00	820.30	126.50	2656.00 m <sup>2</sup>
Grand Total	1,059.95 m <sup>3</sup>			2,656.00 m <sup>2</sup>

Fig.4

### WORKED EXAMPLE FOR PROPOSED DEVELOPMENT OF A 25-STOREY BLOCK WITH 1 BASEMENT CARPARK

$$\text{Concrete Usage Index} = \frac{1,059.95}{2,656.00} = 0.40$$

Calculation for CUI should include all the building elements such as concrete columns / beams and walls / slabs. Figure 4 on the left shows a simplified worked example for CUI calculation.

**Note: The concrete usage for foundation and the basement carpark are not required to be included.**



## EXISTING IT TOOLS USEFUL FOR CUI CALCULATION

### An Introduction

Currently there are commercially available software in both “Building Information Modelling (BIM) Authoring Tools” and “Structural Analysis Engines” which can automatically extract the relevant quantities, such as (1) Volume of Concrete for Superstructures and (2) Constructed Floor Area (CFA) that are needed for the computation of Concrete Usage Index (CUI). Using the BIM modelling and analysis software to extract the relevant quantities will help to ease the complication of computing manually the CUI value which is often time consuming.

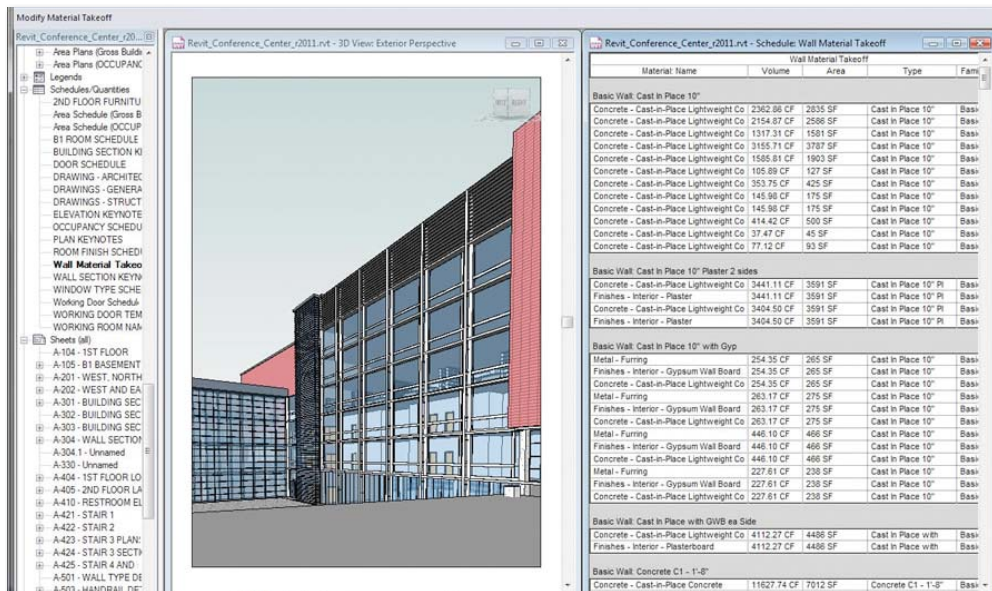
In addition, the accuracy of the automatic quantity takeoff is subjected to the modellers’ level of detail, accuracy in their modelling, the correct definition of the material and the boundary definition of CFA used in the models.

## BUILDING INFORMATION MODELLING (BIM) AUTHORING TOOLS

### 1. REVIT ARCHITECTURE & STRUCTURE

Revit is BIM software developed by Autodesk. It allows the user to design with both parametric 3D modelling and 2D drafting elements. Revit makes use of intelligent models to gain project insight through simulation and analysis and predict performance prior to construction. It also designs accurately using coordinated and consistent information inherent in the intelligent models.

Material Takeoff is a Revit tool under Schedules that helps to calculate and track detailed material quantities which are useful in cost estimates and CUI calculation. The parametric change engine also helps to support more accurate material takeoffs. Figures 5 and 6 on the next page illustrate how material quantity is extracted from schedules generated by models constructed using the software.



**Fig.5 SCHEDULES GENERATED FROM MODELS**

WALL MATERIAL TAKEOFF			
FAMILY AND TYPE	MATERIAL		
	NAME	AREA	VOLUME
BASIC WALL : FOUNDATION • 1'5" CONCRETE	CONCRETE - CAST-IN-PLACE CONCRETE	11353 SF	15673.94 CF
BASIC WALL : FOUNDATION • 3'0" FOOTING	CONCRETE - CAST-IN-PLACE CONCRETE	1177 SF	3118.74 CF
		12530 SF	18792.68 CF
BASIC WALL : EXTERIOR • BRICK ON CMU	CONCRETE - PRECAST CONCRETE	3754 SF	1084.31 CF
BASIC WALL : EXTERIOR • BRICK ON CMU - ENTRANCE	CONCRETE - PRECAST CONCRETE	44 SF	13.14 CF
		3798 SF	1097.44 CF
PENTHOUSE SCREEN WALL : PENTHOUSE SCREEN WALL	FINISHES - EXTERIOR - METAL PANEL	13166 SF	11520.28 CF
		13166 SF	11520.28 CF

**Fig.6 MATERIAL TAKEOFF FOR WALL**

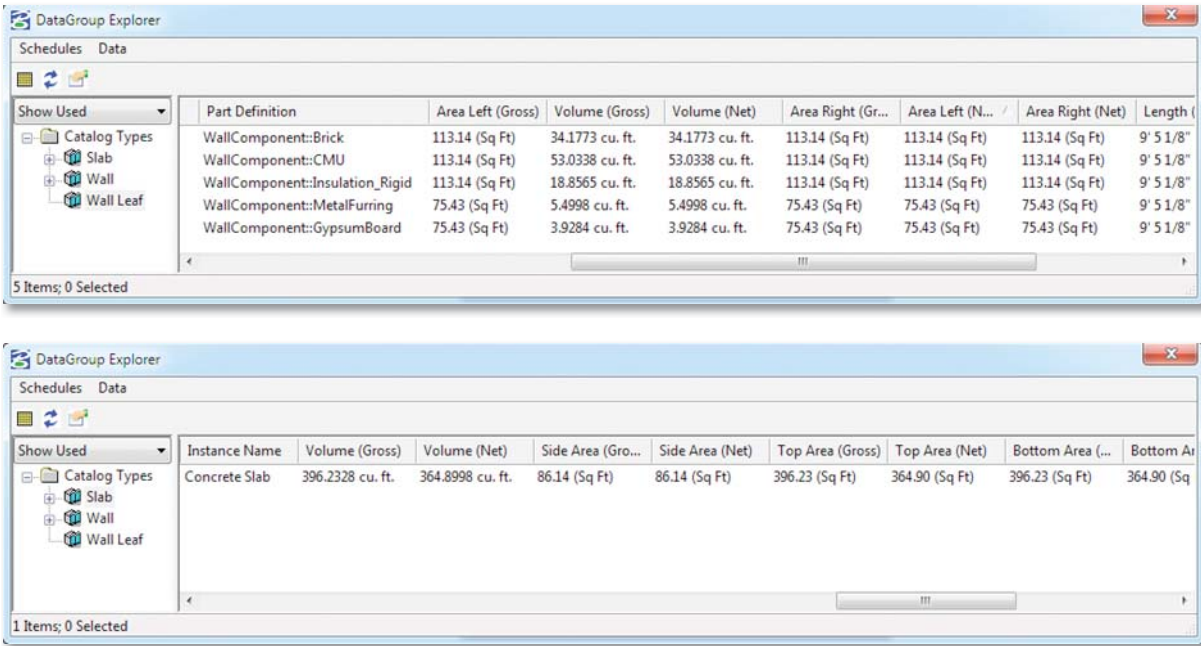
2. BENTLEY STRUCTURE MODELLER / AECOSIM

Bentley Structural Modeller, or AECOsim, is easy to-use BIM application that empowers designers and structural engineers to create structural systems for buildings and industrial plants in steel, concrete, and timber.

The family of applications under AECOsim provides interdisciplinary building design, analysis, and simulation software focused on helping Architectural, Engineering, Construction, and Operations (AECO) work activities.

AECOsim Building Designer provides information rich multi-disciplinary models for use as the centrepiece of a building design workflow, as well as for the integration of design simulation, analysis, and documentation.

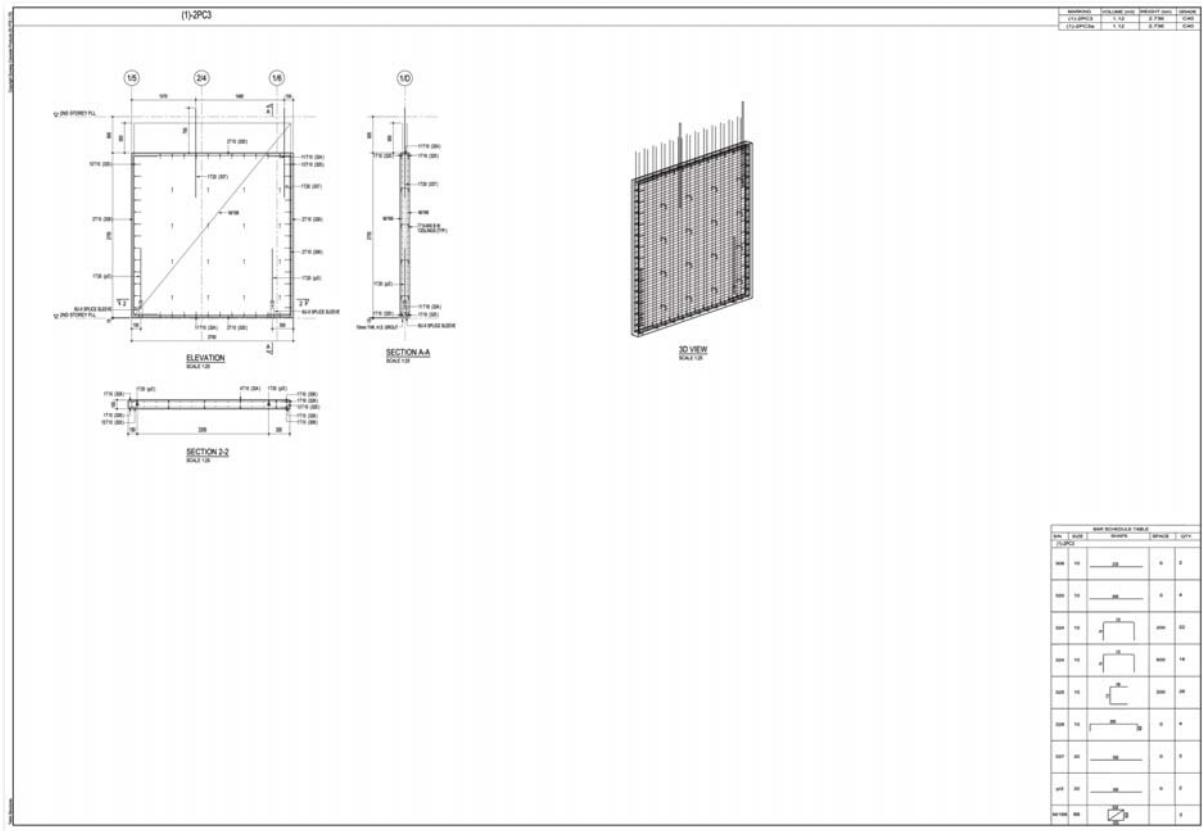
As shown in figure 7, materials quantity can be easily extracted through the Data Group Explorer in addition to using the Quantity Tool under AECOsim.



**Fig.7 MATERIAL TAKEOFF USING DATA GROUP EXPLORER**

### 3. TEKLA STRUCTURES

Formally known as Tekla Xsteel, Tekla Structures is another 3D BIM software used in the building and construction industries for steel and concrete detailing. Tekla models can be used to cover the entire building process from conceptual design to fabrication, erection and construction management.



**Fig.8**

**DRAWING EXTRACTED FROM 3D MODELS USING TEKLA STRUCTURES**





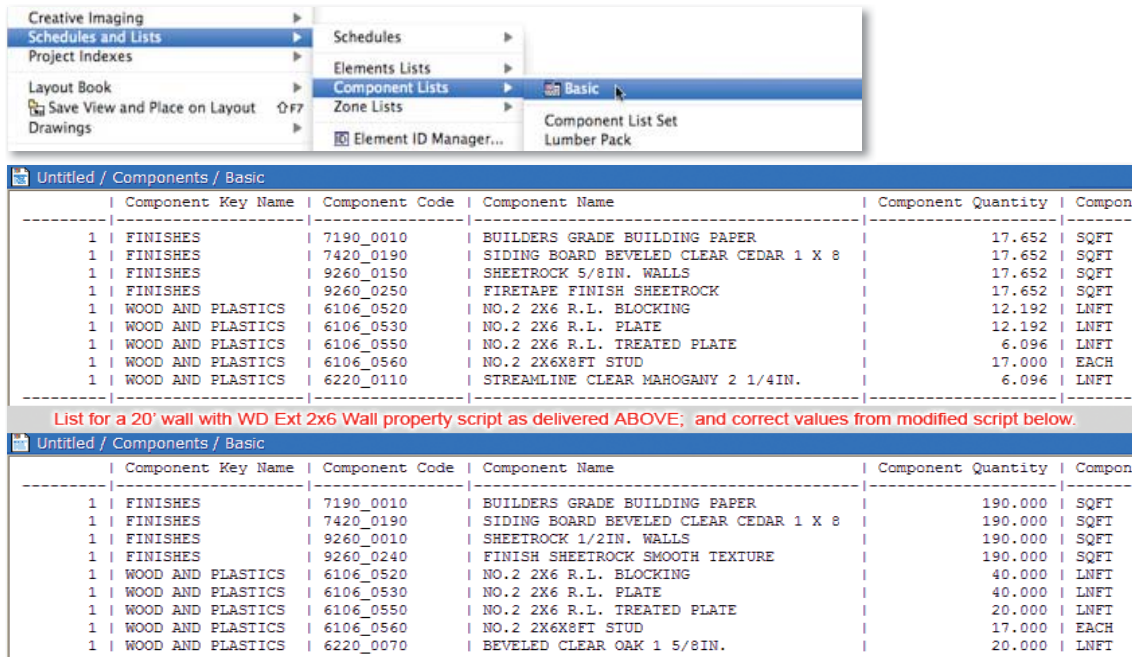
## 5. GRAPHISOFT ARCHICAD

ArchiCAD is an architectural BIM CAD software for Macintosh and Windows, developed by the Hungarian company Graphisoft. ArchiCAD offers specialised solutions for handling all common aspects of aesthetics and engineering during the whole design process of the built environment, for example buildings, interiors, urban areas.

ArchiCAD allows extraction listings from 3D Model through several methods, but the most preferred approach is in the Interactive Schedules. They are defined as a form of query into the model database, where all elements that obey to some selection rule, can be filtered.

Users have control over the parameters to include into the listing and even make some adjustments to the filtered elements from within the list, as shown in figure 10 below.

The result of the list is a table, which can be included in plot sheets or can be exported to another application, such as Microsoft Excel. ArchiCAD model can be exported to BIM-based cost estimation and scheduling through direct API links to 4D and 5D software such as Vico Office Suite or Tocoman iLink.



Component Lists

Basic

Component List Set

Lumber Pack

	Component Key Name	Component Code	Component Name	Component Quantity	Component Unit
1	FINISHES	7190_0010	BUILDERS GRADE BUILDING PAPER	17.652	SQFT
1	FINISHES	7420_0190	SIDING BOARD BEVELED CLEAR CEDAR 1 X 8	17.652	SQFT
1	FINISHES	9260_0150	SHEETROCK 5/8IN. WALLS	17.652	SQFT
1	FINISHES	9260_0250	FIRETAPE FINISH SHEETROCK	17.652	SQFT
1	WOOD AND PLASTICS	6106_0520	NO.2 2X6 R.L. BLOCKING	12.192	LNFT
1	WOOD AND PLASTICS	6106_0530	NO.2 2X6 R.L. PLATE	12.192	LNFT
1	WOOD AND PLASTICS	6106_0550	NO.2 2X6 R.L. TREATED PLATE	6.096	LNFT
1	WOOD AND PLASTICS	6106_0560	NO.2 2X6X8FT STUD	17.000	EACH
1	WOOD AND PLASTICS	6220_0110	STREAMLINE CLEAR MAHOGANY 2 1/4IN.	6.096	LNFT

List for a 20' wall with WD Ext 2x6 Wall property script as delivered ABOVE; and correct values from modified script below.

	Component Key Name	Component Code	Component Name	Component Quantity	Component Unit
1	FINISHES	7190_0010	BUILDERS GRADE BUILDING PAPER	190.000	SQFT
1	FINISHES	7420_0190	SIDING BOARD BEVELED CLEAR CEDAR 1 X 8	190.000	SQFT
1	FINISHES	9260_0010	SHEETROCK 1/2IN. WALLS	190.000	SQFT
1	FINISHES	9260_0240	FINISH SHEETROCK SMOOTH TEXTURE	190.000	SQFT
1	WOOD AND PLASTICS	6106_0520	NO.2 2X6 R.L. BLOCKING	40.000	LNFT
1	WOOD AND PLASTICS	6106_0530	NO.2 2X6 R.L. PLATE	40.000	LNFT
1	WOOD AND PLASTICS	6106_0550	NO.2 2X6 R.L. TREATED PLATE	20.000	LNFT
1	WOOD AND PLASTICS	6106_0560	NO.2 2X6X8FT STUD	17.000	EACH
1	WOOD AND PLASTICS	6220_0070	BEVELED CLEAR OAK 1 5/8IN.	20.000	LNFT

Fig. 10

TABLES GENERATED FROM MODELS IN GRAPHISOFT ARCHICAD

## STRUCTURAL ANALYSIS ENGINES

### 1. BENTLEY STAADPRO

StaadPro is a structural analysis and design computer program originally developed by Research Engineers International (REI) in Yorba Linda, CA. In late 2005, REI was bought by Bentley Systems. It makes use of various forms of analysis from the traditional first order static analysis, second order p-delta analysis, geometric non-linear analysis or a buckling analysis. It can also make use of various forms of dynamic analysis from modal extraction to time history and response spectrum analysis.

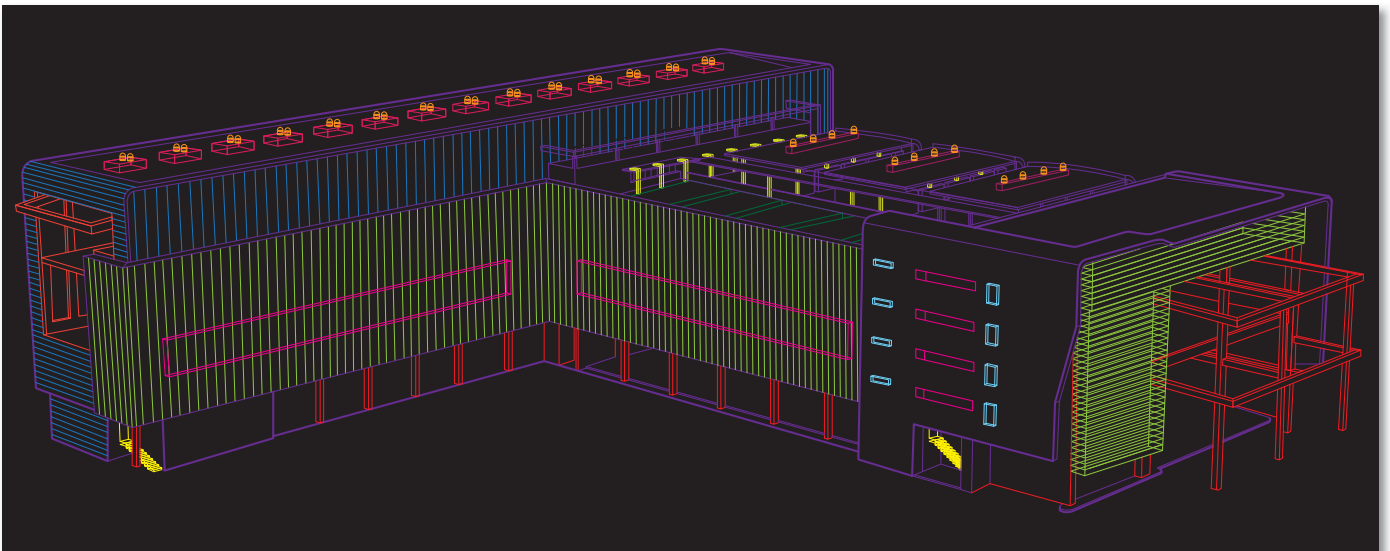
### 2. CSC ORION

Orion is a software for concrete calculations and concrete building design projects. CSC developed this concrete calculation software for engineers supporting both BS codes and Euro codes. Orion has a unique feature capable of producing clear and concise documentation including drawings and quantities. It is also able to export material quantity take-off from concrete, formwork and reinforcement.

### 3. CSI ETABS

Etabs is a type of building analysis and design software. It focused on an "Integrated Building Analysis and Design Environment" system, emphasising on the standards of integration, productivity and technical innovation.

Etabs is capable of producing material list by storey, sorting individual elements like beams, columns and slab and presenting it in a tabulated form.









## SECTION 03

---

# TECHNOLOGIES & METHODOLOGIES

# TECHNOLOGIES & METHODOLOGIES

## Improvements to CUI

### DESIGN FOR OPTIMAL USAGE OF CONCRETE IN STRUCTURAL SYSTEMS

#### 1. PRE-STRESSED CONCRETE ELEMENTS

Pre-stressed concrete refers to the strengthening of concrete by applying predetermined compressive stress in regions where tensile stress in concrete is anticipated due to service loads. This compressive stress is introduced into concrete members using tensioned high tensile strength steel tendons, to offset the tensile stress due to applied loadings. This in turn results in a lower net tensile stress in concrete, allowing an optimisation of structural system such as in having longer member spans or reduced member depths.

There are two methods employed in pre-stressed concrete construction, namely, pre-tensioning and post-tensioning. Pre-tensioning is where tendons are tensioned before placing concrete while post tensioning refers to when the tendons are tensioned only after the concrete has gained sufficient transfer strength.

It is important to note that pre-stressing requires specialised expertise and a high level of quality control and inspection. Hence, it is important that developers or main contractors engage qualified pre-stressing specialist for the design and construction of pre-stressing operations.



**Pic.1** PRE-STRESSED CONCRETE ELEMENTS

## CONTRIBUTIONS TO A LOWER CONCRETE USAGE INDEX

Pre-stressed concrete elements permit considerable reduction in the required size of the member. This encourages materials savings in concrete and steel, which eventually translates to cost savings.

### SAVINGS IN CONCRETE

Due to better deflection control in pre-stressed concrete in comparison with reinforced concrete design, greater concrete member spans are achievable, which in turn also reduces the number of columns and thus allowing for greater unobstructed floor space. With lower net final tensile stresses, reduced effective depths of pre-stressed concrete members are achieved compared to conventional reinforced concrete members. This results in concrete members of smaller dimensions, which translate to savings in concrete.

## OTHER ADVANTAGES

### SAVINGS IN STEEL

As concrete members are pre-stressed using high tensile strength steel tendons to offset tensile stresses due to applied loadings, the amount of reinforcement steel required is typically less than that of a traditional conventional reinforced concrete building.

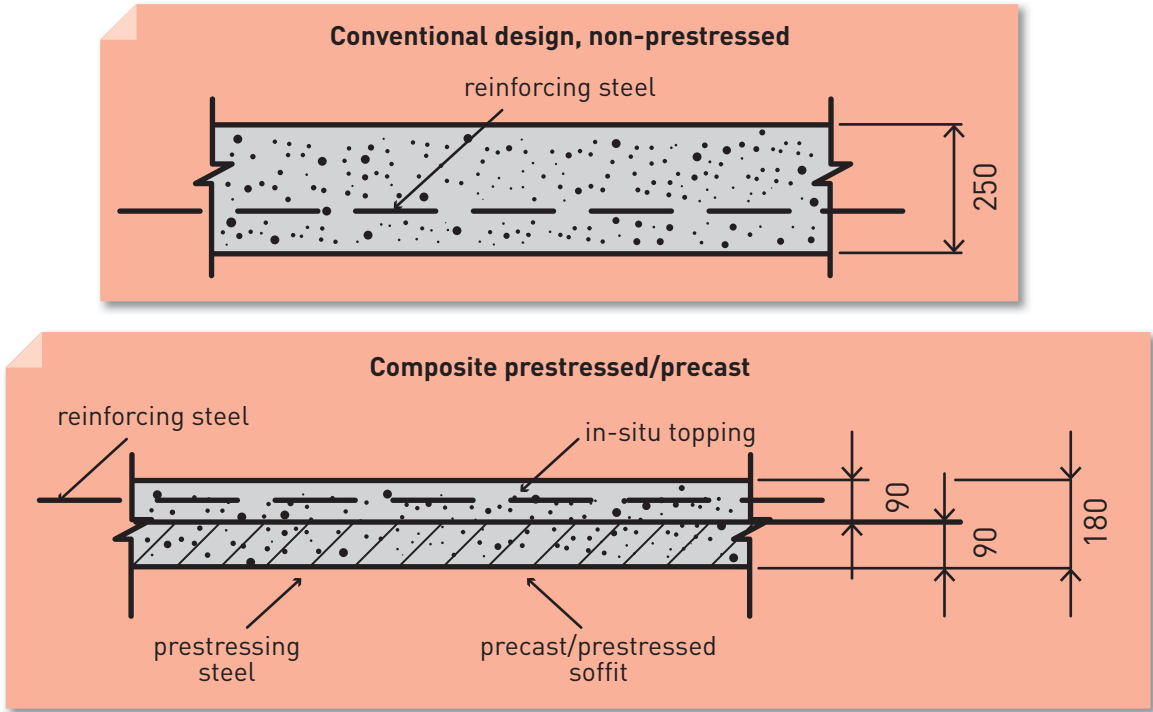
Through a study, the actual material savings can be analysed by considering a typical floor slab and beam as shown in figures 11 and 12 on the next pages respectively.

Figure 11 shows a conventional in-situ floor slab design. In this case, when a composite pre-stressed and precast slab system is considered for the slab system of 8 metres span designed to support a live load of  $4 \text{ kN/m}^2$ , a savings of 28% in concrete volume per square metre and 45% in steel weight per square metre can be achieved.

Figure 12 shows a traditional reinforced concrete beam design, where savings in materials can also be realised by utilising precast and pre-stressed techniques. Considering a 12 metres long precast and pre-stressed beam spaced at 4 metres centres and designed to support a load of  $4 \text{ kN/m}^2$ , a savings of 60.8% in concrete volume per metre and 66% in steel weight per metre compared to a conventionally designed, non-prestressed floor beam of similar span, which is supporting the same loadings.

It is important for projects using composite pre-stressed / precast slabs and beams to consider reduction in mass resulting from reduced reinforcing steel and the addition of pre-stressing steel. The difference in cost for utilising precast and pre-stressed techniques as compared to conventional reinforced concrete member can be significant.





**Fig.11** ANALYSIS USING A TYPICAL FLOOR SLAB<sup>3</sup>

MATERIAL	CONVENTIONAL DESIGN NON- PRESTRESSED	PRESTRESSED / PRECAST	MATERIAL SAVINGS
CONCRETE	0.25 m <sup>3</sup> /m <sup>2</sup>	0.18 m <sup>3</sup> /m <sup>2</sup>	28%
REINFORCING STEEL	18.30 kg/m <sup>2</sup>	6.20 kg/m <sup>2</sup>	45%
PRESTRESSING STEEL	-	3.85 kg/m <sup>2</sup>	45%

Flat slabs (one-way-span)  
Design for live load = 4 kN/m<sup>2</sup>  
Clear span = 8 m

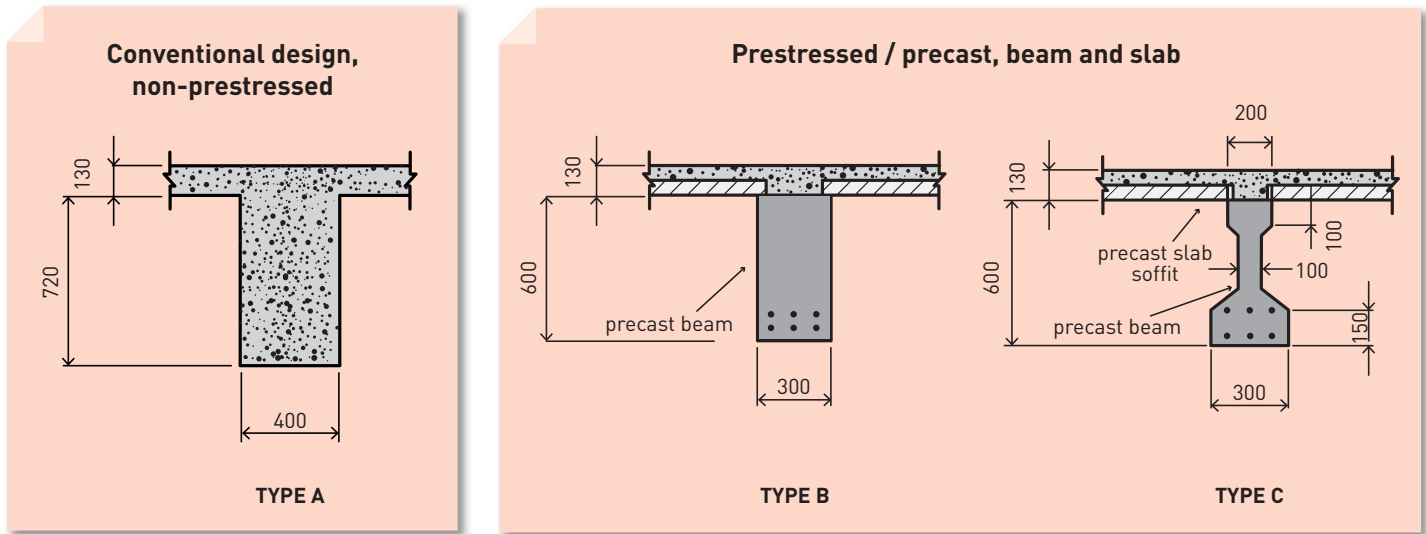


Fig.12

ANALYSIS USING A TYPICAL FLOOR BEAM<sup>4</sup>

MATERIAL	CONVENTIONAL DESIGN NON-PRESTRESSED TYPE A	PRESTRESSED / PRECAST TYPE B	MATERIAL SAVINGS FROM TYPE A TO TYPE B	PRESTRESSED / PRECAST TYPE C	MATERIAL SAVINGS FROM TYPE B TO TYPE C	MATERIAL SAVINGS FROM TYPE A TO TYPE C
CONCRETE	0.288 m <sup>3</sup> /m	0.18 m <sup>3</sup> /m	37.5%	0.113 m <sup>3</sup> /m	37.2%	60.8%
REINFORCING STEEL	42.0 kg/m	6.20 kg/m	66%	6.0 kg/m	-	66%
PRESTRESSING STEEL	-	8.47 kg/m	66%	8.47 kg/m	-	66%

Beams. Span = 12 m  
Clear spacing = 4 m  
centre to centre

Live load = 4 kPa

TECHNICAL CONSIDERATION

Pre-stressed concrete is commonly used for larger loading and longer-span structure.

Study has shown that the two fold effects of longer member span and reduced member depth (high span to depth ratio) contribute to a significant reduction of the building’s self-weight as compared to a traditional reinforced concrete building with the same number of floors to achieve same performance. This indirectly enables a further reduction in member sizes of vertical load resisting members such as columns and the foundation such as piles and pilecaps. Table 1 shows the typical values of span-to-depth ratios in slabs.

In addition, a lower overall building height can also be achieved for the same floor height. This reduces the vertical mechanical and electrical installations, as well as the façade area of the structure which translate into further significant savings in materials and services cost.



Table 01 TYPICAL VALUES OF SPAN-TO-DEPTH RATIOS IN SLABS<sup>5</sup>

PROJECT REFERENCE

JURONG GATEWAY BUILDING

## 2. FLAT SLABS

Flat slab construction originated from the USA. The reinforced concrete flat slab in the early days had drops and columns with capitals, and were considered to be the structure of choice for warehouse construction and heavy loads. Due to the presence of column capitals and slab drops, punching shear failure posed minimum problem.

At a later stage, flat slabs were developed without drops and column capitals. As punching shear failure became dominant, a large amount of research into shear took place and various methods of reinforcing slabs against punching shear failure were developed. Conservative design using flat slab is needed because of the brittle nature of shear failures. Challenges such as the provision of openings or holes near columns as well as deflections, in the flat slab systems, also need to be considered carefully during both in the design and construction stage.



**Pic.2**

**FLAT SLAB CONSTRUCTION**

## CONTRIBUTIONS TO A LOWER CONCRETE USAGE INDEX

Column capitals and slab drops refer to the widened or deepened sections of the columns or slabs at the interface between the columns and the slab. The section acts as a resistance to the punching shear in the slab and, at the same time, increase the stiffness of the slab. Hence, this type of structural system, not only can withstand greater slab loadings making it suitable for industrial and commercial developments, but can also allow the thinner slabs in the design. This helps with savings in concrete used.

The absence of beams also allows lower storey heights, which contributes to a significant amount of material savings in concrete, as well as steel.

Especially in cases where there is no requirement for a deep false ceiling, flat slab construction can minimise floor-to-floor heights. The reduction in the volume of space within a floor will lead to savings in long term operating cost as a result of reduced energy needed for cooling from air-conditioning.

With reduced floor-to-floor heights, a lower building height is attained, with benefits such as further savings in materials and reduced cladding costs. In addition, there is also a reduction of the building's dead load which indirectly makes it possible for a further reduction in size of columns and sub-structures.



## OTHER ADVANTAGES

Flat slab without drops enables faster construction as formwork becomes simplified, compared to a conventional beam-slab system. Architectural finishes can also be applied directly to the underside of slab. This structural system also offers higher productivity onsite due to the simplified installation process of services. This is because flat slab allow the use of prefabricated services to be maximised with uninterrupted service zones at the underside of the slab<sup>6</sup>.

In addition, flat slab construction does not limit where the horizontal services and partitions are placed. This allows the occupier to change internal layouts to accommodate the changes in the use of the internal spaces.

## TECHNICAL CONSIDERATION

Figure 13 on the right shows the different types of flat slab construction such as (i) flat slab without drops, (ii) flat slab with column capitals and (iii) flat slab with drops and their relative spans for economical construction.

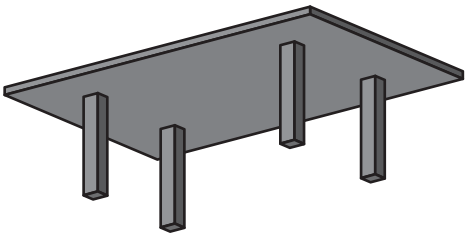
Study has found that generally for the 3 types of flat slab construction, it is economical for square panels of spans ranging from 5m to 10m to be used. Spans beyond 10m would require a thicker slab depth. In order to maintain materials savings and thereby cost savings, integration of flat slab construction with pre-stressing / post-tensioning techniques can be considered so as to achieve a longer span and smaller member sizes<sup>7</sup>.

## PROJECT REFERENCE

**TAMPINES CONCOURSE  
ITE COLLEGE WEST**

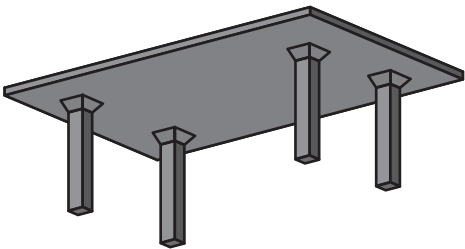
**Fig.13**

### TYPES OF FLAT SLAB CONSTRUCTION AND THE RELATIVE AND THE RELATIVE SPANS FOR ECONOMICAL CONSTRUCTION<sup>8</sup>



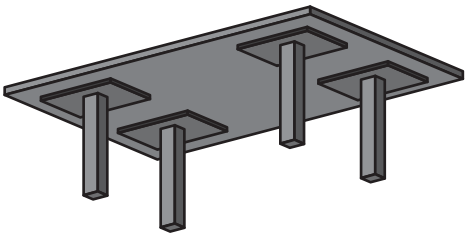
**I. FLAT  
SLAB**

- Very economical for square panels with a span of 5m to 9m
- Popular for office buildings, hospitals, hotels and blocks of flats



**II. FLAT  
SLAB WITH  
COLUMN  
CAPITAL**

- Economical for more heavily loaded spans from 6m to 10m in square panels. However, unless the whole column can be poured at one time, column heads can disrupt cycle times
- Popular for office buildings, retail developments, hospitals and hotels



**III. FLAT  
SLAB WITH  
DROPS**

- Very economical for more heavily loaded spans from 5m to 10m, where square panels are the most economical
- Popular for office buildings, hospitals and hotels

### 3. VOIDED SLABS

Voided slabs are a form of structural slab system in which voids are introduced to reduce the concrete usage, and in turn reduce the dead load of the structural slab. There are in general two types of voided slab, namely hollow-core slab and biaxial voided slab. Other than the two types which are used mainly as structural slabs, the concept similar to that of hollow-core slab can also be applied to produce non-structural lightweight wall panels.



**Pic.3** HOLLOW-CORE SLABS

### HOLLOW-CORE SLABS

Hollow-core slabs as shown in picture 3, are precast concrete slabs with repetitive-shaped voids in a single longitudinal running direction, where pre-stressing techniques are applied to enable the production of larger load bearing hollow-core slabs.

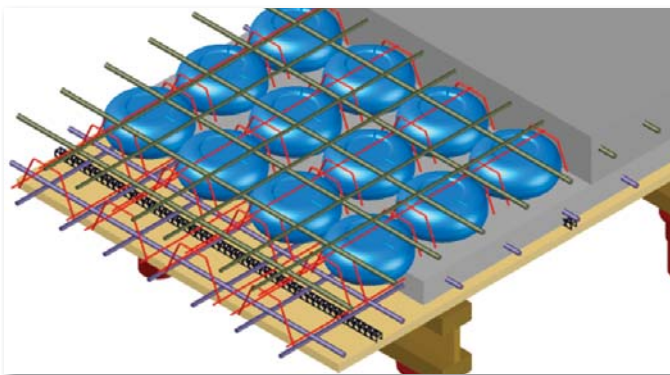
There are mainly two methods of production of hollow-core slab, one method using low slump concrete and the other using normal slump concrete. Dry cast of extrusion system makes use of low slump concrete where the concrete is forced through the machines. The cores are formed by tubes where the concrete are compacted around the cores. On the other hand, wet cast system makes use of the normal slump concrete where the cores are formed by long tubes attached to the casting machines which slip from the cores<sup>9</sup>.

Hollow-core slabs are integrated into the building structure using conventional beam-slab system. This is because live loads can only be transferred in a single direction due to the one-way longitudinal voids.

### BIAXIAL VOIDED SLABS

Biaxial voided slabs as shown in picture 4, are structural slabs where voids are introduced using spherical or torus hollow shells placed in cage modules and which produce a mesh-like structure where loads are transferred in two-way directions. Without reducing the design load capacity of the slab, the voids formed by the hollow shells eliminate part of the dead load of concrete of the slab.

Due to the unique design of the biaxial voided slabs, it can be used as flat slab system in the buildings, thus reducing the dead load of the slab element as compared to a solid flat slab system.



**Pic.4** BIAXIAL VOIDED SLABS

## CONTRIBUTIONS TO A LOWER CONCRETE USAGE INDEX

Applicable to both hollow-core slabs and biaxial voided slabs, the use of these systems in buildings contributes to a reduction in the concrete use due to the presence of the voids. The reduction in the concrete used not only contribute to a savings in concrete materials and cost, it also reduces the dead load component which allows a further reduction in sizes of the supporting columns, as well as reducing the need for a larger foundation.

For biaxial voided slab, it was found that the concrete reduction in slab could range from 25% – 30%.

### OTHER ADVANTAGES

#### HOLLOW-CORE SLABS

The presence of longitudinal voids embedded in slabs acts as a container for the M&E services required for buildings. This contributes to a lower floor-to-floor height, which in turn contributes to a lower building height. With a lower building height, this helps to reduce the specification for M&E services such as a lower capacity for water distribution pumps and ACMV services.

In certain cases when the voids are not located in direction of services route or not big enough to house the service, M&E services conduits may be cast within the concrete toppings.

Precast hollow-core slabs reduce the labour and time needed onsite. This further results in cost savings for the contractor and also increases the productivity onsite.

#### BIAXIAL VOIDED SLABS

Biaxial voided slabs allow a reduction in the concrete usage and cost savings and also pose similar advantages as that of a flat slab system. These include faster construction where the formwork is simplified, and provide greater flexibility for the occupier to change internal floor layouts due to the larger open floor areas.

### TECHNICAL CONSIDERATION

#### HOLLOW-CORE SLABS

Figure 14 on the next page illustrates the structural performance of a typical section of a hollow-core slab, ranging from 150mm to 300mm depth.

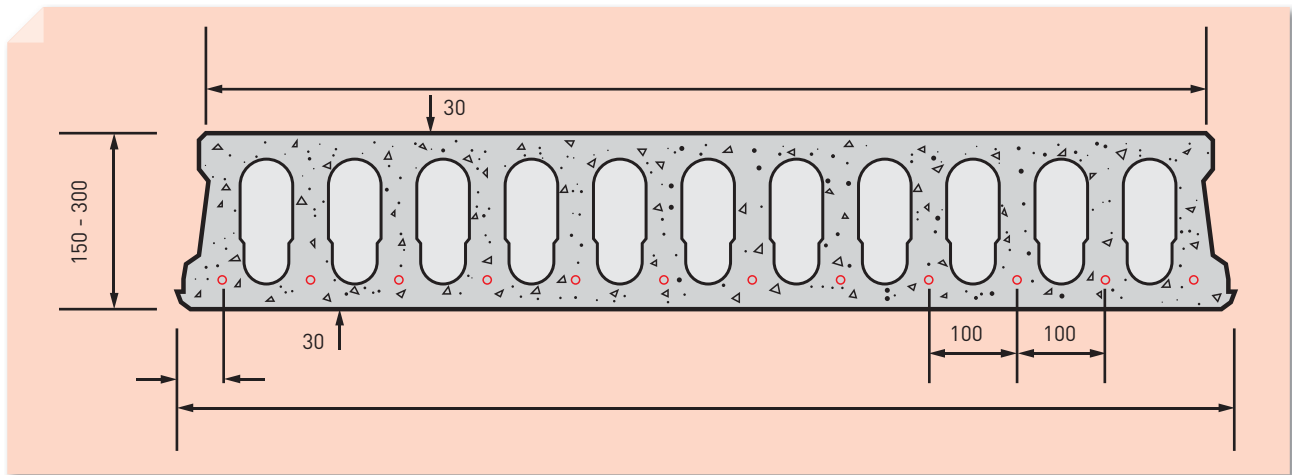
Figure 15 on the next page summarises the relationships between the applied loads (kN/m<sup>2</sup>) to the limiting clear span of different depth hollow-core slab. Self-weight increases with unit depth of the hollow-core slab. When the unit depth is kept constant, limiting span decreases with increased applied loading. As unit depth increases, limiting clear span increases with the same applied load.

#### BIAXIAL VOIDED SLABS

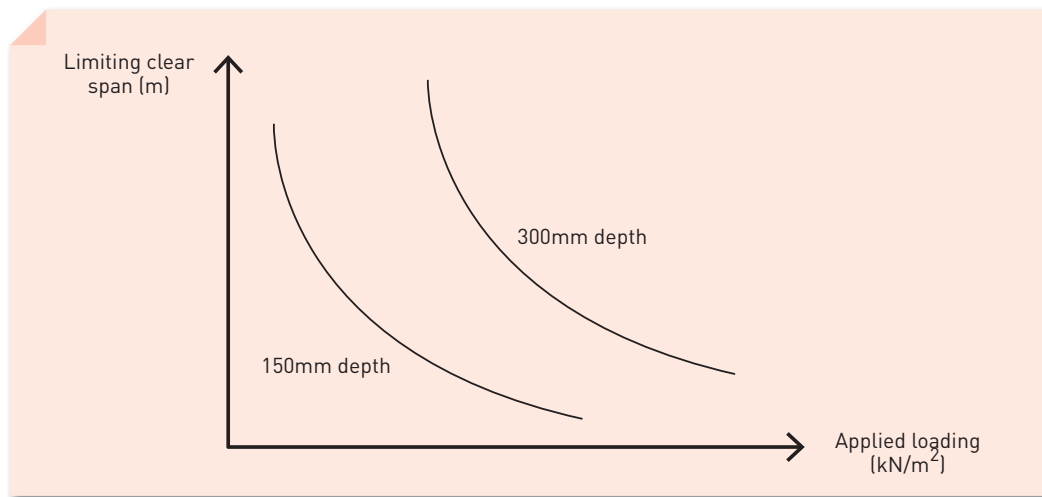
Biaxial voided slabs are usually designed as a flat slab without drop panels, but with span and strength capacity similar to that of solid flat slabs except that they are much lighter structure.

### PROJECT REFERENCE

#### HUNDRED TREES CONDOMINIUM



**Fig.14** TYPICAL SECTION OF A HOLLOW CORE SLAB<sup>10</sup>



**Fig.15** RELATIONSHIP OF APPLIED ( $\text{kN/m}^2$ ) TO LIMITING CLEAR SPAN (m) FOR 150mm TO 300mm UNIT DEPTH HOLLOW-CORE SLAB

## DESIGN FOR OPTIMAL USAGE OF CONCRETE IN NON-STRUCTURAL SYSTEMS

### 1. DRYWALL PARTITION (GYPSUM BOARD AND MAGNESIUM OXIDE BOARD)

Drywall partitions are usually made of recycled materials from a few sources. In general, the manufacturing of drywall partitions requires relatively low energy and hence, it is considered an environmentally friendly product. There are different types of drywall partitions, i.e. gypsum board and magnesium oxide board, the former being most commonly used.

Gypsum board drywall partitions typically contain 85% virgin gypsum, 6% synthetic gypsum, 5% gypsum recycled from manufactured waste and 4% gypsum recycled from construction sites<sup>11</sup>. While virgin gypsum is obtained from mining, the other 15% i.e. synthetic and recycled gypsum come from other sources, such as industrial processes and recycled drywalls.

Sometimes used in building projects to replace gypsum board drywall partitions, magnesium oxide board drywall partitions are made from mineral cement consisting of magnesium and oxygen elements. It is composed of powdered magnesium oxide, water and certain additives placed together in a chemical reaction. Thereafter, the boards which have been casted will be cured at a room temperature. Generally, the source of magnesium can be found worldwide and the production of magnesium oxide boards is energy-friendly as it uses only 20-40% of energy compared to production of Portland cement<sup>12</sup>.



**Pic.5**

**DRYWALL PARTITIONS**



## CONTRIBUTIONS TO A LOWER CONCRETE USAGE INDEX

Calculation for Concrete Usage Index (CUI) omits the use of drywall partitions as non-structural internal walls. However, replacing internal concrete walls with drywall partitions contributes a significant amount of savings for concrete materials, and can in reality leads to a lower CUI value.

In addition to a low energy process product, drywall partitions are lighter in weight as compared to normal reinforced concrete internal walls. This helps to reduce the overall dead load of the building, which allows for a design with thinner structural concrete elements i.e. columns. The overall reduction in the dead load of the building, due to lighter internal drywall partition and slender concrete elements, further allows for a design of foundation with lower load capacity. Not only will these contribute to a reduction in the concrete usage and lower CUI value, it translates to more savings in material as well as structural cost.



**Pic.6** INSTALLATION PROCESS OF DRYWALL PARTITIONS

## OTHER ADVANTAGES

### IMPROVING PRODUCTIVITY

Despite being lightweight, drywall partitions are strong and able to withstand large applied forces. Moreover, the method of installing these drywalls is simpler and faster as compared to normal cast-in-situ concrete walls. In addition, the installation on-site also ensure quality outcome as alignment and connection can be controlled easily during the settling out and stud erection process. Hence, this not only increases the productivity on-site which saves construction time, it also leads to further savings in manpower and construction cost.

In addition, as drywall partitions have smooth surfaces, it only need a thin layer of putty and sanding before it can be painted by using spray or roller method. Unlike the traditional method of construction of concrete wall where plastering is needed before the painting works, there is no need of the usual thick layer of plaster to even out the surface for drywall partitions.

### CONCEALMENT OF SERVICE WORKS

Drywall partitions also promote the enhancement of the aesthetic effect as the two layers board system allows the pipes and cables to be concealed without the messy and time-consuming hacking and patching works which is usually needed in the traditional method of casting concrete walls.

### SOUND INSULATION

By providing rockwool in between the two layers of gypsum boards or magnesium oxide boards, sound-proofing and acoustic performance of drywall partitions can be improved. After the installation of rockwool, the sound transmission class (STC) value is around 45-50. This is even better than the STC value of brick or concrete walls which is around 40.

### GOOD FIRE-RATING

Both magnesium oxide and gypsum boards have high fire resistance as they are entirely non-flammable. Although magnesium oxide boards are able to absorb water, their performance in fire insulation will not be affected in the long run<sup>[13][14]</sup>.

About 21% of the gypsum board by weight is chemically combined water which further adds to its fire resistance. When a gypsum board is exposed to fire, water is slowly released from the board in the form of steam, which slows down the increase in heat gain in the board.

## TECHNICAL CONSIDERATION

To achieve the maximum benefit in drywall construction, the manufacturer's guidelines should be adhered to strictly, especially during the installation process. As projects differ from one another, the suppliers or specialist professionals should be contacted and work closely with for specific advice.

## PROJECT REFERENCE

**TAIPEI 101 (MAGNESIUM OXIDE DRYWALL)**  
**ITE COLLEGE WEST (GYPSUM DRYWALL)**

**SEMI-D at CHANGI**  
**(MAGNESIUM OXIDE DRYWALL)**



**Pic.7** PREFABRICATED BATHROOM UNITS

## 2. PREFABRICATED BATHROOM UNITS

Prefabricated toilet and bathroom system, also known as unitised toilet and bathroom, makes use of an off-site dry construction method, where the production of the components and assembly of the bathroom units are carried out in a dry, spacious and controlled environment, before delivering them to sites for installation. Alternatively, the components of the units could be produced in the factory off-site, then delivered and assembled on site. The assembled units could be delivered on site with complete installation of accessories including sanitary, mechanical and electrical fittings.

Prefabricated toilet and bathroom units have gained popularity since the 1960s, especially in Korea, Japan and Europe. Currently in Japan, each supplier can supply more than 200,000 units of prefabricated toilets per year for residential buildings and another 200,000 units for commercial buildings. There are different types of prefabricated toilet and bathroom systems available in the market today.

1. PRECAST CONCRETE WALL PANELS AND FLOOR PANELS SYSTEM
2. GALVANISED STEEL WALL PANELS AND FLOOR PANELS SYSTEM
3. FIBRE REINFORCED PLASTIC WALL PANELS AND FLOOR PANELS SYSTEM
4. GALVANISED STEEL WALL PANELS AND CONCRETE FLOOR PANELS SYSTEM
5. CEMENT BOARD WALL PANELS AND CONCRETE / FIBRE REINFORCED PLASTIC FLOOR PANELS SYSTEM

## CONTRIBUTIONS TO A LOWER CONCRETE USAGE INDEX

The types of prefabricated toilet and bathroom systems use galvanised steel or fibre reinforced plastic materials which contribute to a reduction in concrete usage as compared to a precast or cast-in-situ concrete wall panels and floor panels system. They not only improve productivity on site but also contribute to a lower concrete usage index.

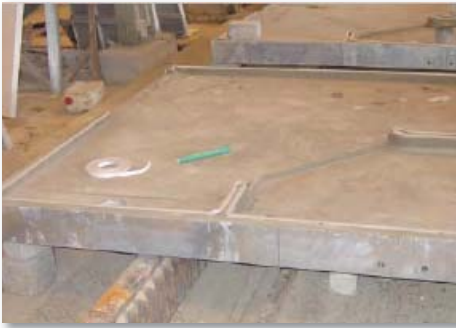
## OTHER ADVANTAGES

In most building projects, toilets or bathrooms involve labour intensive operations. Skilled labour force is required to ensure high quality workmanship and standards in terms of quality finishes and accessories installation, as well as to avoid unnecessary maintenance and water-tightness problems. Conventional methods of construction of bathrooms on-site require sub-contractors to handle various wet works, usually in a constraint working space. In addition, concreting, brickwork, waterproofing, screeding, tiling, plumbing, electrical works have to be carried out separately and systematically involving a lot of coordination work, especially to meet the project schedule.

Since the units are produced and assembled off-site before delivering to site for installation, fabrication of bathroom units can be done in parallel with other works on site. This increases the productivity on site which translates to savings in time for construction and skilled labour, as well as savings in money.

Prefabricated toilets and bathroom systems not only increase the productivity on site, they also ensure consistency of works, especially for tile jointing works when done on-site. Having the components produced in a factory also guarantee better workmanship and quality products. By having the prefabricated toilet and bathroom unit erected off-site allows for off-site inspection and approval of the prototype to be obtained, which remove any potential problems to be encountered on-site. This results in further savings in time, and money.

### **Pic.8 PROCESS OF PRODUCTION FROM FACTORY TO SITE**



**Pic.8.1** BASE CONCRETE  
SLAB CASTING



**Pic.8.2** BASE CONCRETE  
SLAB CASTING



**Pic.8.3** ARRANGE WALL TILES FOR  
FIXING WITH GLUE ADHESIVE



**Pic.8.4** ARRANGE WALL TILES FOR  
FIXING WITH GLUE ADHESIVE



**Pic.8.5** METAL PANELS MOUNT  
ON WALL TILES



**Pic.8.6** METAL PANELS MOUNT  
ON WALL TILES

## TECHNICAL CONSIDERATION

### ACCURACY AND CONSISTENCY IN JOINTS AND CONNECTIONS

In the traditional wet method construction of toilets and bathrooms achieving consistency in structural and architectural works, as well as accuracy in connections of services proved to be challenging and time consuming. In the prefabrication toilet and bathroom systems, these challenges could be overcome.

To achieve consistency in tile jointing, skilled labour is required to place tiles vertically on the already constructed walls using adhesives. This is very time consuming and depends heavily on the skills and experiences of the labour involved. In prefabrication construction, the tiling work is carried out on the horizontal surface directly onto the wall panels of the prefab unit.

In addition, installation of M&E services and waterproofing works are done in the factory that provides a more controlled environment, which contributes to better quality and workmanship.

### GRADIENT IN FLOOR PANELS OF TOILET AND BATHROOM UNITS

Construction of wet areas such as toilets and bathrooms requires a gradient built towards the floor trap to facilitate waste water discharge. In the wet method construction, the gradient is typically formed during the floor screeding using cement-sand mortar. This process of forming the precise designed gradient is very difficult to achieve and time consuming.

In prefabrication construction, the gradient is formed using pre-constructed mould. This eliminates the screeding works which is often time consuming. It also reduces the need for skilled labour and contributes to savings in materials.

## PROJECT REFERENCE

### OCEANFRONT @ SENTOSA COVE TREEHOUSE



## ALTERNATIVE MATERIALS

### 1. STRUCTURAL STEEL

Steel is in essence an alloy of iron and carbon. The production of molten steel is the first step to the manufacturing raw steel products, such as structural sections, plate and wire for construction purposes. There are basically two manufacturing processes of raw steel products, namely the traditional manufacturing process as well as continuous casting process<sup>15</sup>.

Steel is considered as a sustainable structural material due to the: (i) low amount of waste generated during its manufacture and use, (ii) flexibility in its use, (iii) possibility of offsite manufacture, (iv) speed in construction, (v) resource efficiency, (vi) adaptability, (vii) long lasting appeal, (viii) demountability, (ix) safety, and (x) reusability and recyclability, addressing the social, environmental, and economic benefits of the triple bottom line of sustainability.

The traditional manufacturing process is considered to be less efficient and more expensive due to the considerable heat needed to soften the steel. This process involves the casting of molten steel into ingots where after cooling, the moulds are removed. The steel is reheated before being passed through a sequence of rollers to form slabs of steel, whose exact size depends on the intended finished product. Further processing is needed to produce the required engineering sections such as angles, I-beams, plate, sheet metal etc.

In continuous casting process, several steps such as ingot casting, mould stripping, heating in soaking pits and primary rolling are replaced by just one operation: The molten steel is poured into the top of a water-cooled mould.



**Pic.9**

**STEEL USED FOR CONSTRUCTION**

The solidifying steel is drawn through at the bottom in a continuous operation to form the slab before further cooling and rolling into the final cross-sectional shape. This results in considerable savings in energy and production cost when compared to the traditional manufacturing process.

## CONTRIBUTIONS TO A LOWER CONCRETE USAGE INDEX

Using structural steel in construction has clear advantages in terms of lowering the concrete usage index as the use of concrete for such buildings is reduced to a minimum. In a concrete building, the major contribution of concrete comes from the external structural walls and slabs. Hence when the external structural walls are made from steel, reinforced polymer and structural glass materials, the reduction of concrete usage is significant.

## OTHER ADVANTAGES

### PROMOTES SUSTAINABILITY THROUGH RECYCLING / RE-USE

Steel is a 100% recyclable material whose properties do not deteriorate during the recycling process. The use of recycled steel is common in the construction industry. For example in the United States, structural elements such as beams are made from 80% recycled steel<sup>16</sup>. Through recycling steel, not only waste going to landfill is reduced, it also helps in conserving precious natural resources which can be better used for other purposes. In addition, for every kg of steel recycled, 2kg of emission of carbon dioxide, a type of greenhouse gas (GHG) is reduced<sup>17</sup>. For structural steel not damaged in a demolition project can be re-used elsewhere. Hence, the usage of steel in construction promotes sustainability.

### INCREASED SPEED IN CONSTRUCTION AND REDUCTION IN COST

Structural steel frames are lighter than other framing materials, therefore allowing for smaller and simpler foundations. This in turn contributes to a reduction in material costs and an increase in construction speed and a shorter project duration, which leads to reduced costs in terms of construction management services. The use of steel also facilitates an earlier start to the operations of the building, therefore requiring shorter periods for the

recovery of construction costs. The fact that steel quality is not compromised by bad weather conditions allows for a faster erection process, reducing any potential delays and associated costs during construction<sup>18</sup>.

### DESIGN FLEXIBILITY

Steel, with its high strength to weight ratio, has longer spanning capabilities than other materials. This leads to larger areas of unobstructed space which is favourable in countries like Singapore where the amount of land available for construction is scarce. The presence of large areas of unobstructed space also makes it easier to subdivide and customize space for rental purposes. Another property of steel is its ductility, which allows the curving and bending of steel, offering opportunities for elegant architectural designs to be incorporated within building façades. This architectural freedom is heightened by the diversity of steel components which are now economically feasible with the use of CAD programs and computer-controlled processes. Unprecedented combinations of steel components are now also possible through precision fabrication. Furthermore, any existing steel components can be easily reinforced by bolting or welding additional steel to bear more load and new steel designs can be incorporated to the building façade as building trends change<sup>19</sup>.

## TECHNICAL CONSIDERATION

### CORROSION

Steel corrodes in the presence of oxygen and water. Corrosion rates depend on the length of time during which the surface is wet and the type and amount of atmospheric pollutants, (i.e. sulphates, chlorides etc)<sup>20</sup>.

To prevent galvanic corrosion, buildings are designed where contact between steel and materials which cause corrosion, is not allowed. Details which can potentially trap moisture and debris, (i.e. joints) can be welded instead of being bolted when it is exposed to external environment.

### FIRE RESISTANCE

Strength of steel decreases at high temperatures, (i.e. at 550°C, steel reduces 40% of its strength) Research done in this area has shown that there is not a specific temperature at which steel loses its strength but a range during which the temperature profile and the load applied play an important role in the reduction of strength<sup>22</sup>.

Fire resistance is tackled in two ways: (i) Fire-resistant design, and (ii) fire protection. Fire-resistant design involves the calculation of the predicted performance of structural steel and survival times, based on material properties at high temperatures. Since the fire performance depends on the applied load, structural dimensions, stress distribution, and temperature distribution of the steel structure, these factors can be taken into account when designing for fire resistance.

The second method of fire protection involves the insulation of the steel structure which is designed in a normal manner, enabling the steel structure to maintain a low temperature during a fire<sup>23</sup>.

Additionally, paint or metallic coatings, which protect against corrosion, can be applied to steel. To enhance coating performance, surface preparation which takes into account surface cleanliness, surface profile / amplitude, surface dust and surface condition immediately before coating, is performed before coating<sup>21</sup>.

### SOCIAL BENEFITS

Since its construction takes place under fast-paced, clean and relatively quiet conditions, construction of steel structures cause minimum disruption to the surrounding communities. This process usually takes place in relatively small teams of skilled workers who manufacture and fabricate the steel components offsite in a consistent manner which is preferable in terms of health and safety. The premises housing the steel industry (e.g. manufacture and fabrication) are integrated into their surrounding local communities, creating job opportunities by continuously training new workers and contributing to the local economy.

## PROJECT REFERENCE

**OUB CENTRE**

**UOB PLAZA**

## 2. HIGH STRENGTH CONCRETE

High Strength Concrete (HSC) is a type of specially designed concrete mix which achieves a compressive strength of more than  $60\text{N/mm}^2$  (note: quoted concrete strengths are characteristic cube strength)<sup>24</sup>. The preceding code of practice for concrete design, CP65/ BS8110 only allows the concrete grades to be capped at  $60\text{N/mm}^2$ , hence in response of the rising trend of use of High Strength Concrete in building projects, BCA released a guide for design of High Strength Concrete (BC2:2008) in year 2008. Eurocode 2, the newly adopted design standards, allows for the design of high strength concrete of grades up to  $105\text{N/mm}^2$  [25].

### CONTRIBUTIONS TO A LOWER CONCRETE USAGE INDEX

HSC as compared to normal strength concrete demonstrates higher load bearing capacity, which allows for a reduction in the number and also cross sectional area of structural elements such as columns and beams. This in turn can translate into savings in concrete used, as well as usable floor area, both contributing to a lower Concrete Usage Index. In addition, the reduction in concrete usage can also result in a lighter superstructure. As the self weight of the superstructure is reduced, it allows for a reduction in the requirement of the structural foundation capacity such as shallower pile penetration depth and smaller pilecaps, which in turn contributes to a further reduction of concrete usage for the building project.

### OTHER ADVANTAGES

Net savings in the overall cost of building the HSC structure can be achieved due to high reduction in material quantity, despite the higher material rates for HSC compared to normal grade concrete. HSC also enables the early removal of formwork due to its rapid strength gain during construction, resulting in a shorter cycle time. This indirectly contributes to significant site operation cost savings and improvement in productivity on-site.

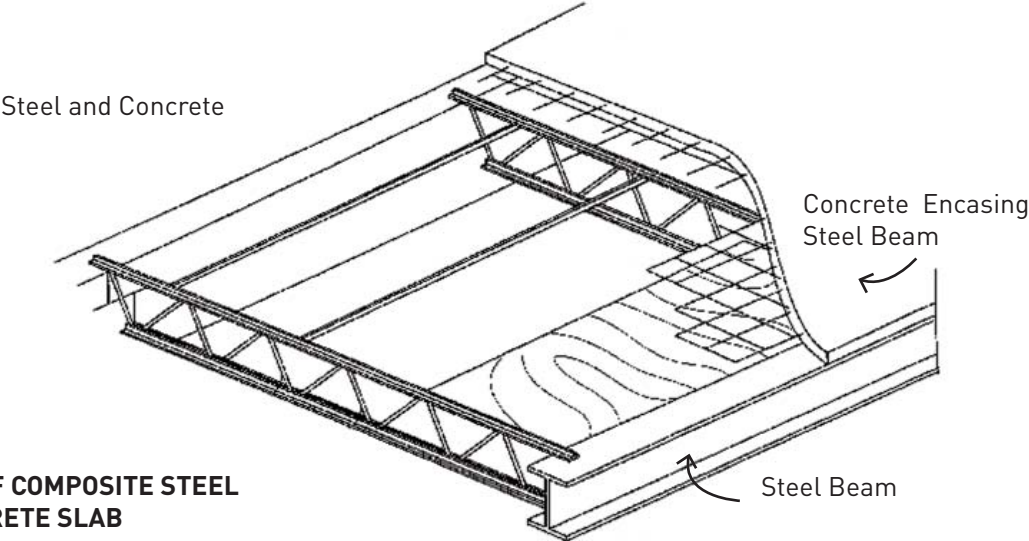
### TECHNICAL CONSIDERATION

As compared to normal grade concrete, the production of HSC demands a greater emphasis on quality control<sup>26</sup>. Hence, strict quality monitoring and control measures at the concrete mixing plant must be in place to ensure the success of producing the HSC mixes. In addition, during on-site construction, it is crucial to pay more attention to ensure adequate compaction of the HSC mixes and avoid potential plastic shrinkages, by covering the finished concrete surfaces with water retaining curing agents.

For the construction of HSC building works, it is important that in-situ concrete strength tests are carried out in order to verify the compliance with the designed concrete strength. This includes the hammer tests, ultrasonic pulse velocity measurement and other non-destructive tests. It is also a common practice to use superplasticizer and water-reducing retarder during the production of HSC<sup>27</sup>. As HSC entails low water-cement ratios, the superplasticizer gives the concrete adequate consistency (workability) and also greater increase in the concrete strength. On the other hand, the water-reducing retarder slows down the hydration process of the cement, which allows more time for the handling of the concrete on-site during casting.

### PROJECT REFERENCE

#### THE SAIL (75MPa CONCRETE)



Pic. 10

SECTION OF COMPOSITE STEEL AND CONCRETE SLAB



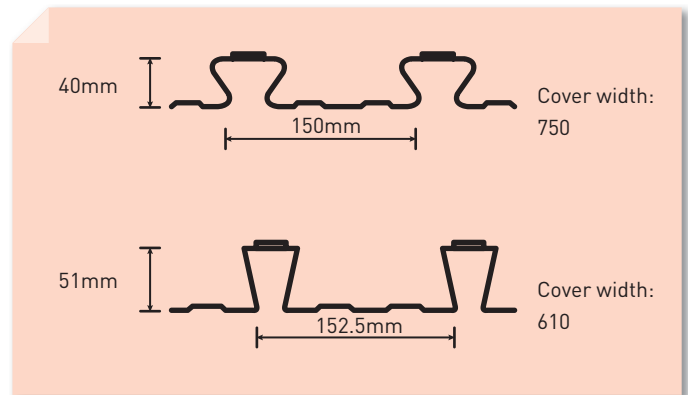
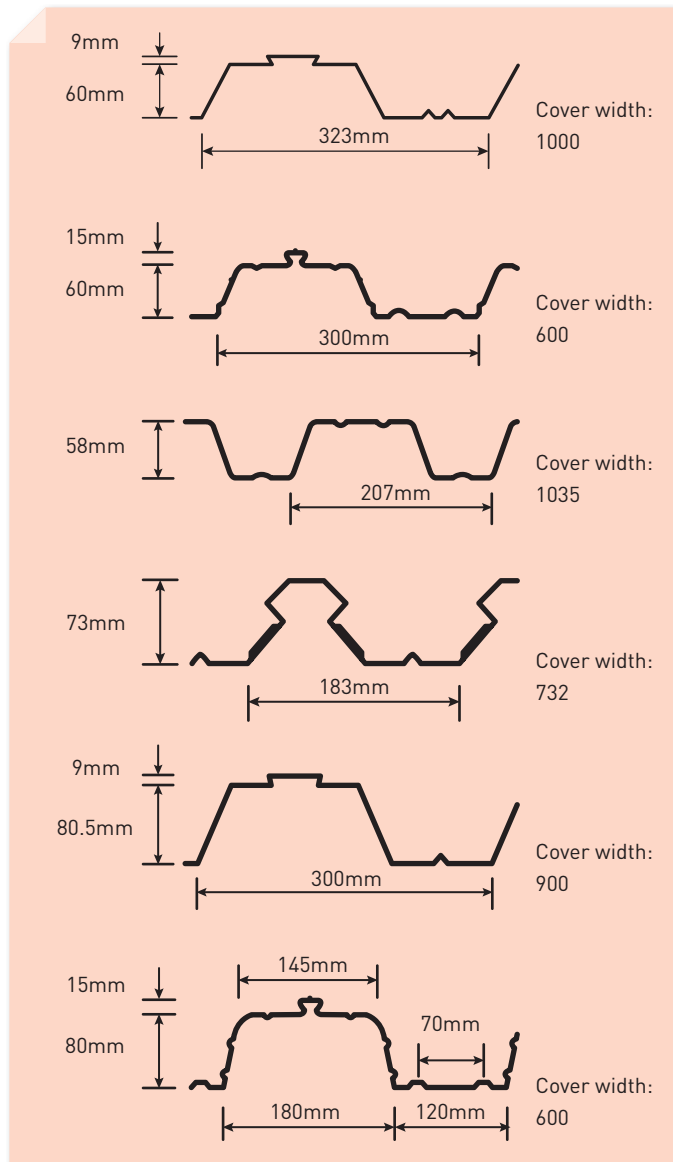
3. COMPOSITE MATERIALS

Composite materials are two or more materials mixed together, producing properties better than the individual materials it was made from. Traditionally, there were two methods of construction namely conventional concrete construction method and construction in steel. Both conventional methods had its own disadvantages such as sensitivity to tensile force for concrete construction and low fire resistance for steel construction. However, with the composite of steel and concrete, these limitations can be overcome. Typical steel-concrete composite structural elements include composite slabs, composite beams and composite columns such as concrete filled steel tube and encased steel section, and composite wall systems.

A composite member is able to withstand the external loading through an interaction of bonds and friction. In most composite construction, only the steel portions are used to support the primary loads of construction. Thereafter, concrete is cast around or filled into the steel sections. After the concrete hardened, the composite section is capable of resisting the full design load. Steel-concrete composite beams may appear in three different forms, steel beam is completely encased in concrete, partially encased or totally not encased. In the totally not encased situation, the steel beams are placed underneath the concrete slab. This results in a lighter structure of both steel and concrete as compared to a conventional concrete structure. Steel-concrete composite building may be designed to resist horizontal loads preventing the building from swaying or deflecting easily<sup>28</sup>.



For a composite slab, there are various profiled steel sheets as shown below in figure 16. The various slabs differ in stiffness and resistance performance. There are mainly two categories of profiled steel sheets, namely open through profiled steel sheets and re-entrant profiled steel sheets.



**Fig.16** OPEN THROUGH PROFILE STEEL SHEETS AND RE-ENTRANT PROFILED STEEL SHEETS FOR COMPOSITE SLABS<sup>29</sup>

Composite columns may take the form of open sections partially or fully encased in concrete, or concrete-filled hollow steel sections. It is advantageous to use high-strength concrete together with high-strength steel to resist compression load. This would lead to smaller column footprint and thus create more usable space.

Besides steel-concrete composite, there is polymer matrix composite. Polymer matrix composites comprises of polymer and a reinforcement material or particulate material or both. Reinforcement material includes various fibres such as glass, carbon and natural fibres<sup>30</sup>. Particulate material consist of sand, talc, colour chips, recycled glass etc. These materials tend to be corrosion resistant, light and has a good environmental durability with high strength-to-weight ratio. Most of these composite are used for facades, interior walls and design, floors, etc.

## CONTRIBUTIONS TO A LOWER CONCRETE USAGE INDEX

In contrast to conventional concrete structures, the use of take-off composite design would reduce significantly the amount of concrete used in construction. In addition, since the steel component is able to withstand both tensile and shear forces better than concrete, lesser amount of concrete is needed to encase the steel component to support the same construction load as compared to conventional concrete slabs.

## OTHER ADVANTAGES

In addition to lowered concrete usage index, the stiffness of composite beams is more than the conventional ones. Thus, in turn it allows composite beams and slabs to be shallower and thus the building height can be reduced based on the same GFA or same number of storeys. Thus façade area and its cost can be reduced. Such façade costs are vital for monetary savings as it may take up as much as 20% of the total cost of building<sup>31</sup>.

Compared to traditional pure steel structure, the manufacturing of steel and concrete composite expends less energy in the process. An I-beam steel structure which uses 237MJ of energy to manufacture only needs 109MJ of energy for a composite structure that can withstand the same load<sup>32</sup>. Hence, composite material greens the environment by expending less energy than traditional methods.

The thickness of cross sections would not be affected with different loads and resistances as the thickness of steel, amount of reinforcement and concrete strength determines the load capacity. Therefore, the same cross section of a column can be constant throughout all the storeys of a building. This makes the process of construction easier and requires a shorter construction period due to its simplicity to erect the structure. In addition, there will not be any formwork needed to cast the concrete for tubular sections as the steel structures will be used in place of formwork. Without the use of formwork, production costs are reduced as no material and labour cost is involved in the fabrication and erection of formwork.

## TECHNICAL CONSIDERATION

### FIRE RESISTANCE

The fire resistance of steel section can be achieved by providing adequate concrete encasement. Though concrete filled steel tube (CFST) columns have added fire resistance as compared to hollow steel tubes, CFST typically still cannot achieve adequate fire resistance.

This problem can be overcome by providing fire reinforcement inside the columns or encase the steel tube with fire protection materials depending on the load level. Composite slab can achieve the required fire rating without providing fire protection to the metal deck. This can be achieved by providing additional reinforcements in the concrete slab<sup>33</sup>.

### CORROSION

Corrosion can occur in CFST by means of crevice corrosion or by pitting. The typical culprits of reinforcement corrosion are chloride ions and carbonation by carbon dioxide. To tackle this problem, the use of hot dip galvanized, epoxy-coated or stainless steel rebar, good design and appropriate cement mix, cathodic protection and the use of fly ash will be helpful<sup>34</sup>.

## PROJECT REFERENCE

**OUB CENTRE**

**REPUBLIC PLAZA, SINGAPORE**

**CAPITAL TOWER, SINGAPORE**

**ONE RAFFLES LINK BUILDING**

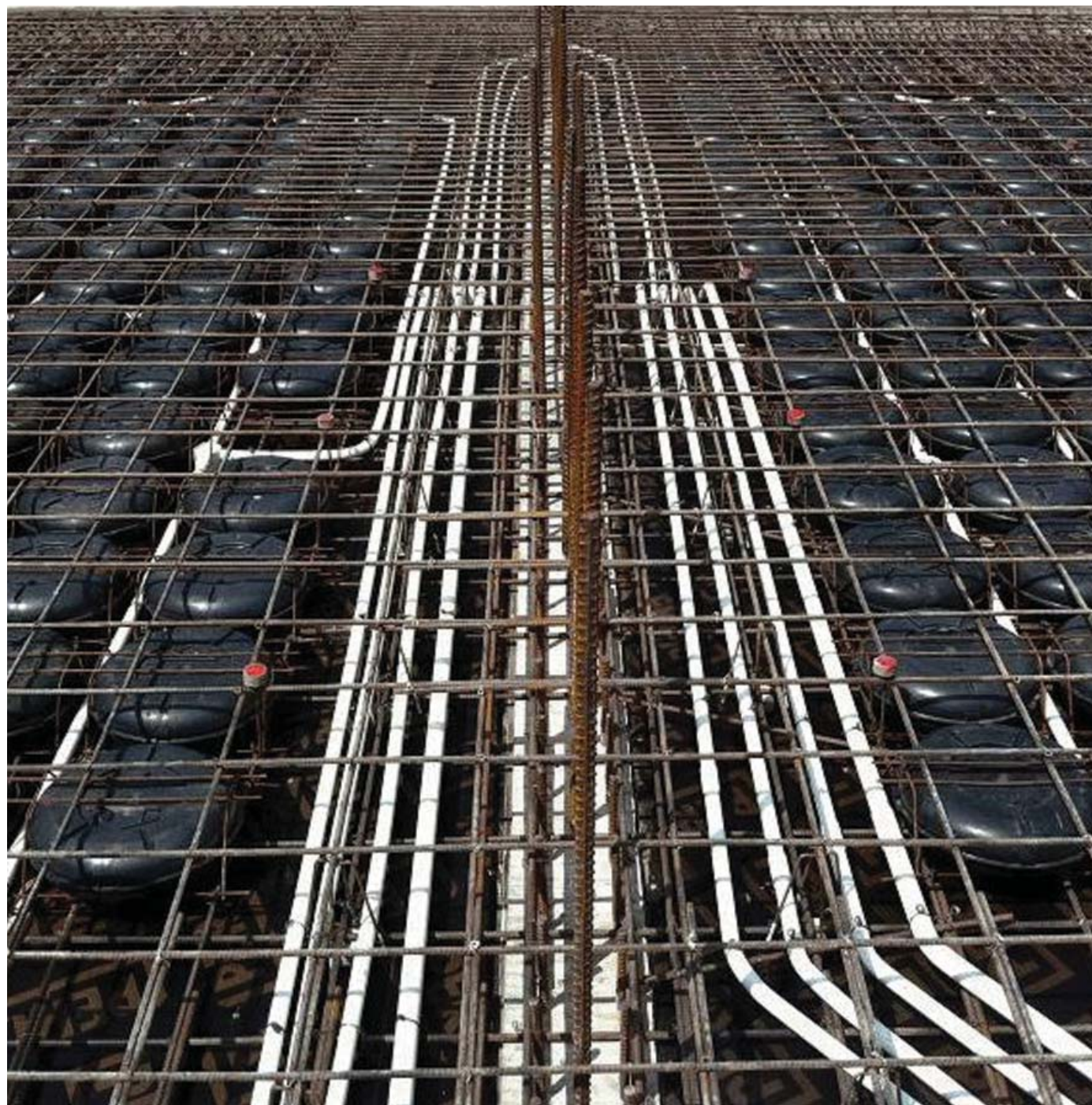
### SERVICEABILITY ISSUES

Stresses in composite sections as well as cracking, and deflections of composite structures need to be taken into account.

Stresses can be approximated by  $\sigma = M_{E1}/W_{ae} + M_{E2}^2/W_{ac}$ , where  $M_{E1}$  is the self-weight moment on the unpropped beam and  $M_{E2}$  is the moment from the imposed loads and finishes. The equation is simplified to  $\sigma = M_E/W_{ac}$  for propped construction. For concrete, the compressive stress should be limited to prevent longitudinal cracking and significant effects. For steel, there are no specific restrictions for the stresses in the steel element but extra factors need to be accounted for when calculating deflections if yield is reached.

Crack widths in concrete elements must not exceed about 0.3mm for durability and aesthetic purposes. The equation for crack width  $w_k$  can be approximated by  $w_k = s_r (\epsilon_{sm} - \epsilon_{cm})$ , where  $s_r$  is the maximum crack spacing,  $\epsilon_{sm}$  and  $\epsilon_{cm}$  are the mean strains in the reinforcement and in the concrete between cracks respectively<sup>35</sup>.

Deflections should be restricted to ensure that the appearance of the structure is not badly affected. The typical criterion is for the maximum deflection not to exceed span/250 and the usual reference point is the underside of the beam<sup>36</sup>.



## SECTION 04

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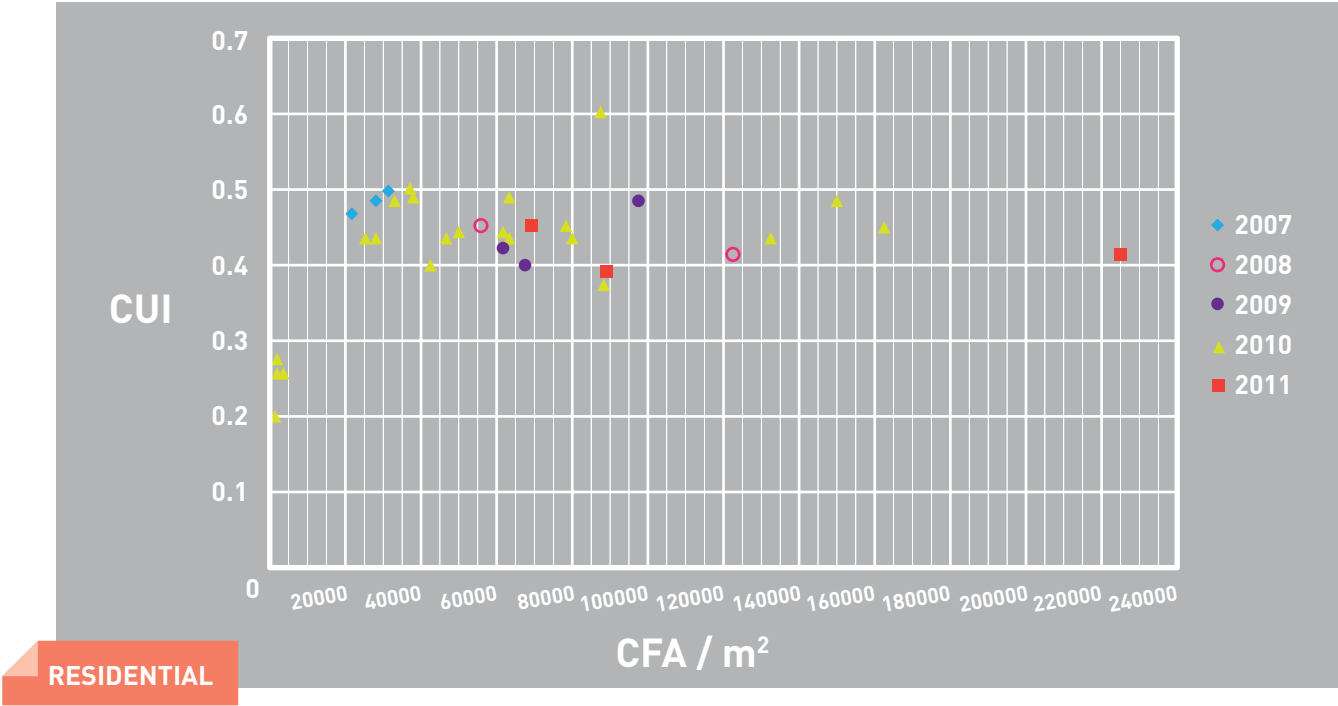
# GOOD PRACTICES ON CUI



# GOOD PRACTICES ON CUI

## TRENDING RESULTS FOR CUI

Figures 17 and 18 show the trending results for past residential and non-residential projects, achieving GM Platinum and Gold<sup>Plus</sup> awards, from year 2007 to year 2011. This section will also highlight a few projects which are able to achieve low CUI and good buildability scores, without resorting to steel construction.

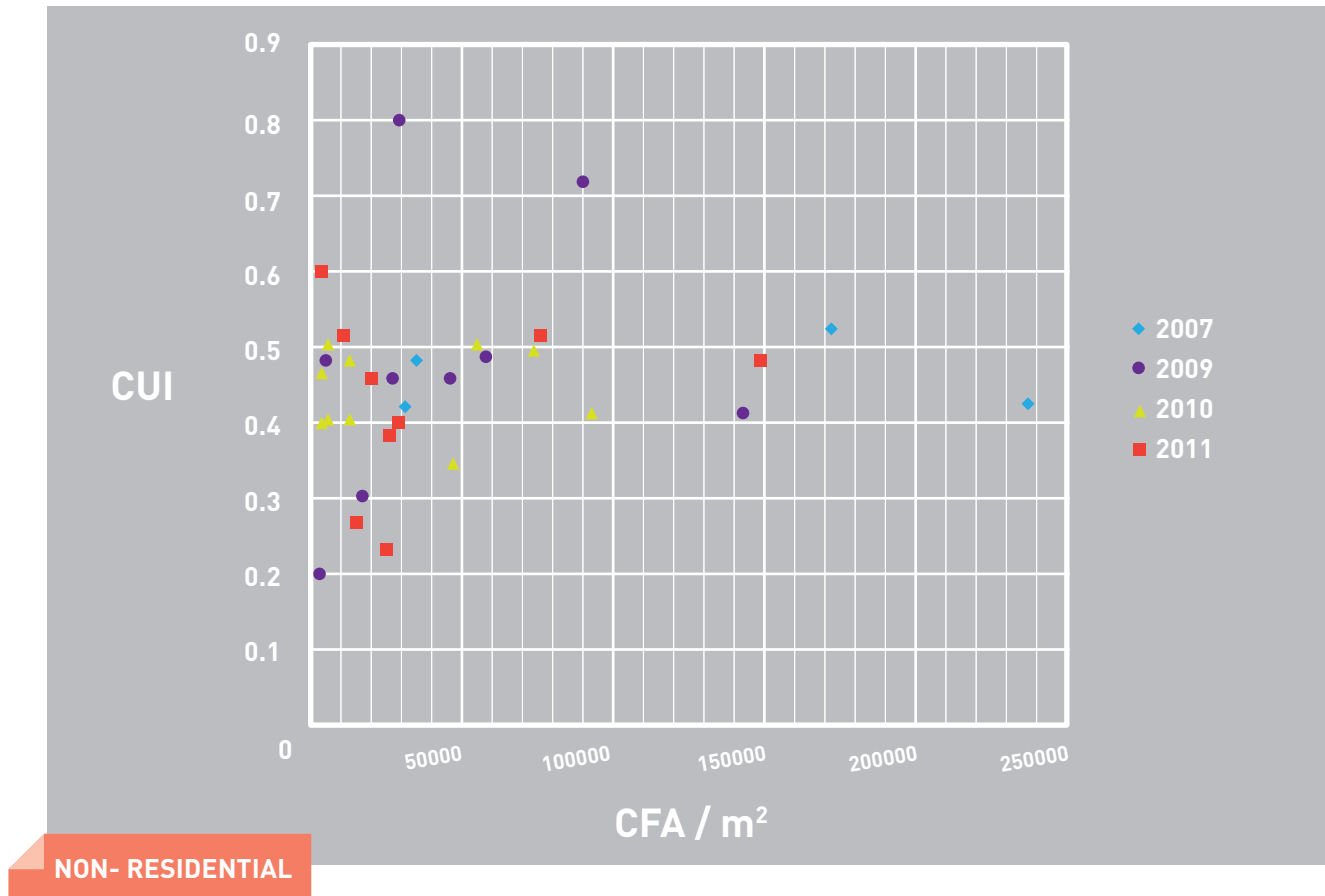


**Fig.17 CUI DATA FOR RESIDENTIAL PROJECTS ACHIEVING HIGHER TIER GM AWARDS**

It can be observed that from 2007 to 2011, residential projects can achieve CUI values in the range of 0.38 to 0.5, with a large concentration of projects with constructed floor area (CFA) of less than 100,000m<sup>2</sup>.

There is no distinctive observation that CUI values improve with smaller CFA, however, it is noted that the lower storeys development usually can achieve lower CUI values, especially residential landed, as shown by the 3 data points of CUI range from 0.2 to 0.28.





NON- RESIDENTIAL

**Fig.18 CUI DATA FOR NON-RESIDENTIAL PROJECTS ACHIEVING HIGHER TIER GM AWARDS**

There is a large concentration of non-residential projects with CUI range from 0.38 to 0.5. Similar to residential projects, it can be observed that lower-storey developments can achieve better CUI values, as shown by the data points of 0.2 to 0.3 which consist of mostly industrial projects with 3 storeys and less.

## PROJECT EXAMPLES

### TAMPINES CONCOURSE



Concrete Usage Index: 0.31  
Buildability Score: 81  
Green Mark Award obtained: Gold<sup>Plus</sup>

**Pic. 11**

**TAMPINES CONCOURSE**

#### PROJECT TEAM

Developer:	City Developments Limited
Architect:	Architects61 Pte Ltd
Structural Consultant:	LSW Consulting Engineers Pte Ltd
M&E Consultant:	Conteem Engineers Pte Ltd
Contractor:	Dragages Singapore Pte Ltd
TOP Date:	14th January 2009
CSC Date:	4th February 2009

## PROJECT DESCRIPTION

The project was a 3-storey office complex in a parcel of land between Tampines Avenue 5 and Tampines Concourse. The total constructed floor area achieved for this building was 17,601.2m<sup>2</sup>. The unique requirement for this office complex was to build it as a “green building”, where engineering design and materials were aligned to make construction eco-friendly and efficient. Majority of the building was built for office space, and the layout of building consists of toilets, escape stairwells, and lifts located in the centre of the building. The consumer switch room and MDF room were built on the left wing in the first storey. The only utility located outside the building was the substation constructed next to the car park. The building also had a 3 metre-wide covered walkway for the entire perimeter of the building that was up to 3 metres wide.

## LOW CONCRETE USAGE INDEX

To achieve low CUI, a new alternative to structural design was adopted to reduce the amount of concrete used for the construction. The design not only performed its function of carrying load, but it was able to reduce cost in general construction. Overall concrete used per square metre was reduced and with it lower CUI compared to the conventional method.

Designed for office requirements, the building’s main air-con ducts and water pipes and other M&E services run underneath each storey slab. To cater for the design, and to optimise the maximum floor height with the utilities, a hollow core slab system was used instead of the conventional running beams that would be required to support the long span.

The hollow-core slab system proved to be a design that was first able to take the loading for a 13.5m long span (distance from column to shear core wall) and for the transverse axis, it was designed to carry load bearing length of 9m. It also weighed significantly less than the in-situ slab of equivalent loading requirement.

Adopting the hollow core slab design not only saved on the use of raw materials but it generated overall savings in construction cost.



**Pic. 12**

### SAVINGS IN SCAFFOLDINGS DURING CONSTRUCTION

The reduced slab weight led to the need for lighter structural framing and greatly reduced the load to be carried by pile foundations. Through this slab system, the number of piles was reduced by at least 10-13%. In addition, the number of scaffoldings required during the course of construction was reduced. This was possible because the precast hollow core slab is able to serve dual purposes through its functions as a formwork that spans across beams. See picture 12 above depicting how this was performed on-site.

## GOOD PRACTICES

The use of 'Green Concrete' in Tampines Concourse helps achieve the goal towards constructing a green building.

The components of green concrete used for construction were as follows:

### 1. NORMAL CONCRETE

The whole-substation located outside the building.

### 2. SEMI-GREEN CONCRETE

(only 10% copper slag + 20% ground granulated blast furnace slag (GGBS)) – primary structures that include all columns, walls, pre-cast beams (including those with downhang).

### 3. GREEN CONCRETE

(10% copper slag + 20% recycle crushed aggregate + 20% GGBS) – secondary structures such as hollow-core slab topping, pre-cast planter box (used on the typical storey), pre-cast parapet, pre-cast staircase, pre-cast façade and the link-way reinforced concrete slab.

### 4. ECO-CONCRETE

(30% copper slag of fine aggregate + 20% recycled coarse aggregate + 20% GGBS) – non-structural components such as apron drain, footpath, reinforced planter box (1st storey), road kerbs and lean concrete



**Pic. 13**

**PRECAST CONCRETE HOLLOW-CORE PLANKS WITHOUT THE NEED OF SCAFFOLDINGS**



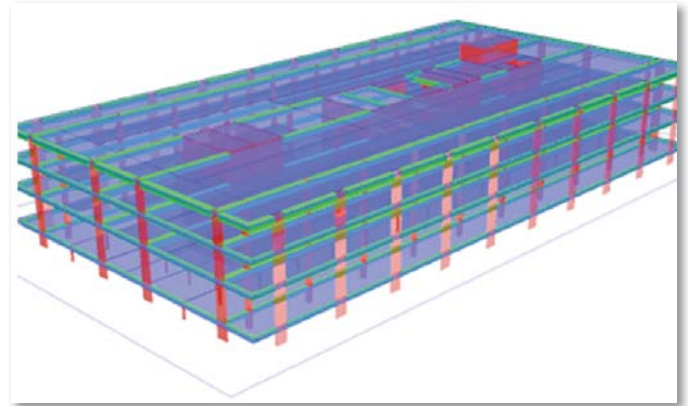
**Pic. 14**

**NEAT HOUSEKEEPING DUE TO EASY STORAGE OF HOLLOW-CORE SLABS**

## SOFTWARE USED TO CALCULATE CUI MORE EFFICIENTLY THAN THE CONVENTIONAL MANUAL CALCULATION

The modelling software used to build and analyse this project was a 3-D Building Model called Orion by CSC. This software performed detailed analysis and conduct calculations to accurately define the self-weight and stiffness of the hollow-core slab to reflect the weight reduction from this structural system.

Through Orion, the software enabled the Architectural layout to be placed in the background of the structural model, as shown in the figure below, to scale. The structural model was then built on top of the architectural layout, which ensured accurate length and sizes of structural members to be accounted for, and thus a very quick method to trace the concrete volume used in the overall development for concrete usage index calculation.



**Fig.19** ANALYSIS MODEL USING ORION

## SUPPLIERS' CONTACT

### **PRECAST ELEMENTS SUPPLIER :**

**EASTERN PRETECH PTE LTD**

15 Sungei Kadut Street 2

Singapore 729234

### **RECYCLED MATERIALS SUPPLIER :**

**PAN UNITED CONCRETE PTE LTD**

9 Tampines Industrial Street 62

Singapore 528815

**ITE COLLEGE  
WEST**



Concrete Usage Index: 0.42  
Buildability Score: 71  
Green Mark Award obtained: Platinum

**Pic.15** ITE COLLEGE WEST

**PROJECT TEAM**

<b>Developer:</b>	<b>Gammon Capital West Pte Ltd</b>
<b>Architect:</b>	<b>DP Architects Pte Ltd</b>
<b>Structural Consultant:</b>	<b>Beca Carter Holdings Pte Ltd</b>
<b>M&amp;E Consultant:</b>	<b>Ferner (S.E. Asia) Pte Ltd</b>
<b>Contractor:</b>	<b>Gammon Pte Ltd</b>
<b>TOP Date:</b>	<b>29th March 2010</b>
<b>CSC Date:</b>	<b>21st June 2011</b>



## PROJECT DESCRIPTION

ITE College West is a 9.54-hectare campus located at Choa Chu Kang. It is currently accommodating 7,200 full-time students, 8,100 part-time students and 630 staff in its compound. There are many facilities available to cater for both students and staff. This includes automotive showroom, training cells, 22-room training hotel, visitor reception centre, training restaurants and kitchen, commercial outlets, laboratories and workshops. In addition, it has a 680-seat theatre-styled auditorium, a centre for music and arts with production and dance studios and a sports village complete with gymnasium, running track, indoor sports hall and an Olympic-sized swimming pool.



**Pic.16**

**CONSTRUCTION OF POST-TENSIONED BEAM AND PRECAST HOLLOW-CORE SLAB IN PROGRESS**

## LOW CONCRETE USAGE INDEX

There were mainly two factors which contributed to the reduction in CUI for ITE College West Campus, namely the use of (i) post-tensioned flat slabs and pre-tensioned beam systems, and (ii) the use of hollow-core slabs for the structural systems.

Regular building grid of 8.4m x 8.4m in Block 1 and Block 2 enable the use of post-tensioned flat slab to be used extensively. Where columns are skipped at the auditorium level, post-tensioned beam and slab systems are adopted. The use of post-tensioning systems results in more efficient structural size and optimisation of concrete usage.

For repetitive rectangular grid of 8.9m x 13.2m at Block 4, 5 & 6 and 8.4m x 11.2m at Block 7, precast pre-tensioned hollow-core slab on post-tensioned beam system was adopted. The use of precast pre-tensioned hollow-core slab greatly reduced the concrete usage of floor elements. Similarly the same structural system was repeated for the curvilinear Block 3 of grid varied from 9m x 12m to 13m x 14m for efficient concrete usage. The use of precast pre-tensioned hollow-core slab reduced formwork and wet work on site.

Using grade 50 concrete and pre-stressed strands, hollow-core slabs met the long span grid requirement with efficient structural depth and reduced dead weight. To cater for the various designed loadings and spans, hollow-core slabs of 265mm, 325mm and 360mm thick were used with 75mm thick structural topping for composite action. The hollow-core slabs were designed as simply-supported ends seating on post-tensioned beams.

## GOOD PRACTICES

As an environmentally friendly alternative to the traditional reinforced concrete walls, the reinforced earth wall was used for a total length of 486m along the site boundary. Similar to the traditional reinforced concrete wall, it resisted lateral earth pressures while providing adequate foundation bearing capacity. Moreover, it incorporated the connection strength of interlocking modular keystone units together with a geo-grid system of earth compaction. This method thus decreased the amount of steel reinforcement and in-situ concrete used and allowed a planting zone above the geo-grid reinforcement within 3m of the wall perimeter.

Eco-concrete was used in place of traditional concrete wherever possible. It consisted of recycled washed copper slag and was used for the non-suspended slabs at external landscape areas.



*Pic.17*

### CONSTRUCTION OF REINFORCED EARTH WALL IN PROGRESS

## SUPPLIERS' CONTACT

### PRECAST PRE-TENSIONED HOLLOW CORE SLAB :

#### EASTERN PRETECH PTE LTD

15 Sungei Kadut Street 2  
Singapore 729234

### KEY STONE RETAINED EARTH SYSTEM :

#### VSL SINGAPORE

25 Senoko Way  
Woodlands East Industrial Estate  
Singapore 758047

### ECO-CONCRETE :

#### HOLCIM SINGAPORE PTE LTD

16 Jalan Tepong  
Singapore 619331

## HUNDRED TREES CONDOMINIUM



Concrete Usage Index: 0.42  
Buildability Score: 85  
Green Mark Award obtained: Platinum

**Pic.18** HUNDRED TREES CONDOMINIUM

### PROJECT TEAM

<b>Developer:</b>	Grande-Terre Properties Pte Ltd
<b>Architect:</b>	Ong&Ong Pte Ltd
<b>Structural Consultant:</b>	KTP Consultants Pte Ltd
<b>M&amp;E Consultant:</b>	Squire Mech Pte Ltd
<b>Contractor:</b>	Tiong Seng Contractors Pte Ltd
<b>TOP Date:</b>	To be confirmed
<b>CSC Date:</b>	To be confirmed

## PROJECT DESCRIPTION

With a GFA of 43,751.61m<sup>2</sup> including balconies, Hundred Trees Condominium is a 396-unit flat development comprising of apartments ranging from 1 to 4 bedrooms and penthouses. The design is known to come from an eco-conscious approach. These apartments are housed in six blocks of 12-storey and two blocks of 11-storey at West Coast Drive, built over the footprint of old Hong Leong Garden.

## LOW CONCRETE USAGE INDEX

With the aim of reducing CUI, this development was built on raised landscape deck with half basement excavation works kept at its minimal. A transfer beam system was chosen over the transfer plate system to lower concrete usage. However, an extensive transfer beam system was not needed as most of the supporting columns or walls had been brought down to the pile foundations. Moreover, all the non-structural structure elements such as internal drains, pavements and road kerbs used recycled concrete aggregate.

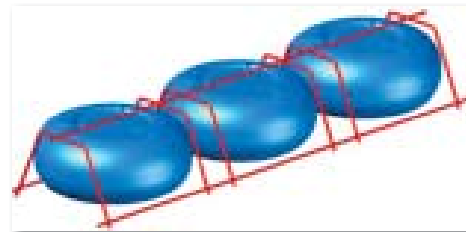
The Cobiax system was employed in this project to reduce 800m<sup>3</sup> of concrete volume which indirectly reduced the emission of 160 tonnes of CO<sup>2</sup>. This involved the use of 230mm thick cobiax slabs with grade 40 concrete adopted. A slab design incorporating 100mm voids was used as compared to 225mm solid slab in the original design.

There was also the extensive use of precast technology not only in structural but also architectural and prefabricated bathroom units. Structural elements such as beams, columns, walls, RC ledge and balcony were prefabricated in precast yard and installation done on site. More than 80% of the toilets were prefabricated bathroom units, completed with sanitary wares, fittings and accessories, floor and walls finishes. With these precast elements, less plastering was required as they have better finishing.

In addition, the project also used drywall partition from Fiberock USG, made from 95% recycled materials. It was used as an economical alternative to concrete block and plaster construction. The drywall also contributed to an overall reduction in the dead load for the building.

### BRIEF INFORMATION ON COBIAX TECHNOLOGY

The patented Cobiax Technology helped to optimise the overall building efficiency through the positioning of hollow void formers modules within concrete slabs which reduced unnecessary dead load in the concrete slab of the structure. Appropriate placement of the cobiax void formers contributed to dead weight reduction without modifying flexural strength and biaxial load transfers to supports.



**Fig.20** COBIAX VOID FORMERS IN POSITIONING CAGES TO ALLOW EASY PLACEMENT ON SLABS



Cobiax product line Cobiax Slim line comes in various sizes and is suitable for use in slabs thickness of 200mm up to 400mm or more, with dead load reduction in the range of 1.4 to 2.8kN/m<sup>2</sup>. For easy on-site handling, Cobiax void formers comes in positioning cages to allow easy placement on the slabs. In addition, this is a flexible system which allows for execution by traditional in-situ concrete or in combination with precast-elements. It is able to accommodate embedded M&E services and other elements embedded within the slabs.

For Hundred Trees Condominium, the void formers were in 7 numbers per modular cage for ease of installation and handling, where the void formers were taken out to accommodate the development's embedded M&E services, as illustrated by pictures 19 and 20. It is important that during the planning stage, both cobiax slab layout and M&E routine are coordinated and defined properly before the actual installation on site.

## COST IMPLICATIONS

The cost of the Cobiax cage modules was offset by direct and indirect savings. Direct savings were derived from the reduced usage of concrete and re-bars. This ultimately led to the indirect benefits of the whole building structure, such as smaller beams, thinner vertical supports due to overall lighter weight.

## SUPPLIERS' CONTACT

**COBIAX SYSTEM :**  
**COBIAX TECHNOLOGIES (ASIA) PTE LTD**  
 510 Thomson Road #08-00  
 SLF Building Singapore 298135

**USG FIBEROCKS DRYWALL PARTITION :**  
**PACIFIC INTERIORS SUPPLY PTE LTD**  
 47 Jalan Buruh, CWT District Park  
 Office Block #01-02 Singapore 619491



**Pic.19** INSTALLATION OF COBIAX MODULES



**Pic.20** EMBEDDED M&E SERVICES WITHIN COBIAX VOID FORMERS



**Pic.21** LAYING OF COBIAX IN PROGRESS



**Pic.22** COBIAX WITH WALKING PLATFORM



**Pic.23** LIFTING OF PRECAST WALL



**Pic.24** POSITIONING OF PRECAST WALL



## PUNGGOL WATERFRONT TERRACE



Concrete Usage Index: 0.46  
 Buildability Score: 81  
 Green Mark Award obtained: Platinum

**Pic.25** PUNGGOL WATERFRONT TERRACE

### PROJECT TEAM

<b>Developer:</b>	Housing Development Board
<b>Architect:</b>	Aedas Pte Ltd
<b>Structural Consultant:</b>	Beca Carter Holdings
<b>M&amp;E Consultant:</b>	Ferner (S.E Asia) Pte Ltd
<b>Contractor:</b>	Tiong Seng Contractors (Pte) Ltd
<b>TOP Date:</b>	Mid of Sep 2014
<b>CSC Date:</b>	End of Sep 2014

## PROJECT DESCRIPTION

This Waterfront development located at Punggol is a 19-storey building that comprises of 1074 units of dwelling apartments with one level of basement car park. The total construction area is 224,500m<sup>2</sup>. The client requirements included a score of 80 for minimum buildability by adopting the usage of precast pre-stressed plank, precast façade, precast beam and column, a maximum CUI of 0.46 and the use of an alternative structure since transfer structure had not been permitted.

## LOW CONCRETE USAGE INDEX

A lower CUI was attained through the use of precast pre-stressed planks to reduce the slab thickness. This in turn reduced the concrete usage by approximately 20%, as compared to a flat slab design. The use of transfer structures was avoided as the concrete usage for these structures were high. The floor to floor height was also limited to 2.8m to minimise vertical loads. Furthermore, recycled materials such as recycled concrete aggregate were used for non-structural elements such as concrete paths and road stoppers.

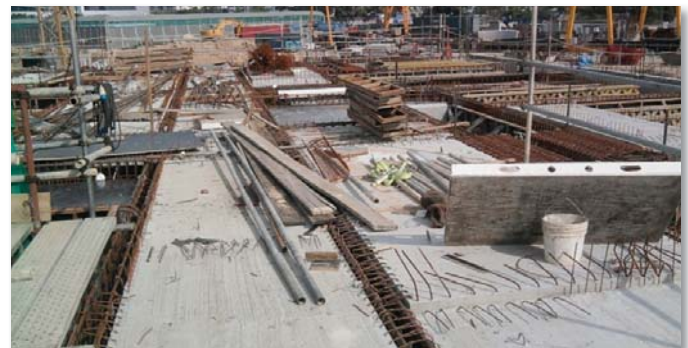
## SUPPLIERS' CONTACT

**PRECAST PRE-STRESSED PLANKS :**  
**ROBIN VILLAGE DEVELOPMENT PTE LTD**  
 5 Toh Guan Road East #02-02  
 Singapore 608831



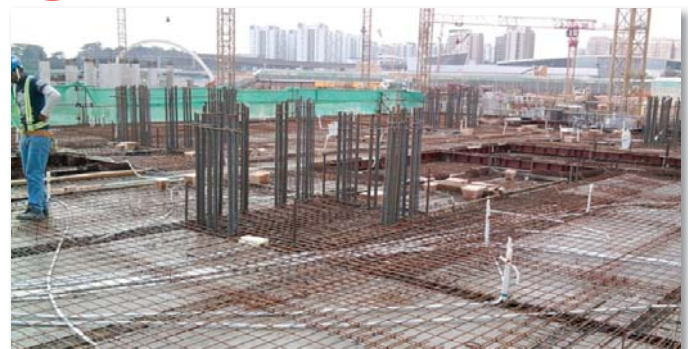
**Pic.26**

**LAYING OF PRECAST  
PLANK IN PROGRESS**



**Pic.27**

**COMPLETION OF INSTALLATION  
OF PRECAST PLANKS**



**Pic.28**

**PRECAST PLANKS WITH  
TOP REINFORCEMENT**

## WOH HUP BUILDING



Concrete Usage Index: 0.46  
 Buildability Score: Not applicable as project is less than 2,000m<sup>2</sup>  
 Green Mark Award obtained: Platinum

**Pic.29** WOH HUP BUILDING

### PROJECT TEAM

<b>Developer:</b>	<b>Woh Hup Holdings (Pte) Ltd</b>
<b>Architect:</b>	<b>RSP Architects Planners &amp; Engineers (Pte) Ltd</b>
<b>Structural Consultant:</b>	<b>RSP Architects Planners &amp; Engineers (Pte) Ltd</b>
<b>M&amp;E Consultant:</b>	<b>Squire Mech Pte Ltd</b>
<b>Contractor:</b>	<b>Woh Hup Pte Ltd</b>
<b>TOP Date:</b>	<b>8th June 2011</b>
<b>CSC Date:</b>	<b>2nd July 2012</b>

## PROJECT DESCRIPTION

Woh Hup Building is a 4-storey commercial office development with facilities which include a rooftop solar garden that is integrated with a landscape garden. This building aimed to become a high performance building equipped with highly integrated active and passive design features. This building is recognized for its many green features such as the reliance on natural daylighting to 55% of the building, the advanced building controls and environmental management system which displays the building's performance in real time and the use of Solyndra cylindrical solar modules as a trellis at the rooftop garden to create a Solar Garden.



## LOW CONCRETE USAGE INDEX

Concrete walls facing Northeast and Southeast were replaced by aluminum curtain wall and brickwall with insulation respectively, thus achieving a low CUI in this development. Concrete was used for columns, beams, slabs, lift cores, staircase cores and planter walls only. Lesser concrete was used internally as the office layout followed an open plan. Any other necessary internal concrete walls were replaced with drywall partitions or Compac green wall. Therefore, Woh Hup Building achieved a low CUI of 0.46 without resorting to the usage of steel elements.

## GOOD PRACTICES

The percentage of recycled concrete aggregate (RCA) used differed in the various parts of the building. First-of-its-kind concrete comprising of 30% RCA and 30% washed copper slag (WCS) was used for the superstructure elements of the building. This saved 524 tonnes of coarse aggregate and 350 tonnes of sand. Non-structural elements such as drains and pavements used 50% RCA and 50% WCS which translates to a saving of 74 tonnes of coarse aggregate and 50 tonnes of sand.

Compac green wall was developed and patented by National University of Singapore (NUS) under the joint MND Research Fund administered by BCA. The wall was produced by an optimal extrusion technique, which resulted in a homogeneously well-compacted cross-section for increased strength and robustness.

**Pic.30**

**VIEW TOWARDS SKY TERRACE**



**Pic.31**

**GLASS PARTITION FROM  
OFFICE TO SKY TERRACE**

## SUPPLIERS' CONTACT

**ALUM WORKS :**  
YUANDA ALUMINIUM INDUSTRY ENGINEERING  
(SINGAPORE) PTE LTD  
76, Shenton Way, #16-02 Singapore 079119

**DRYWALL PARTITION :**  
PANFRAME (S) PTE LTD  
3016 Bedok North Ave 4, #04-22 Eastech Singapore 489947

**Pic.32**

**INTERIOR VIEWS OF WOH HUP BUILDING**

**TUAS RV -  
PREFAB HUB**



Concrete Usage Index: 0.46  
Buildability Score: 84  
Green Mark Award obtained: Platinum

**Pic.33** TUAS RV - PREFAB HUB

**PROJECT TEAM**

<b>Developer:</b>	<b>Robin Village Development Pte Ltd</b>
<b>Architect:</b>	<b>LOOK Architects Pte Ltd</b>
<b>Contractor:</b>	<b>Tiong Seng Contractors (Pte) Ltd</b>
<b>Structural Consultant:</b>	<b>LSW Consulting Engineers Pte Ltd</b>
<b>M&amp;E Consultant:</b>	<b>HPX Consulting Engineers Pte Ltd</b>
<b>TOP Date:</b>	<b>5th April 2012</b>
<b>CSC Date:</b>	<b>To be confirmed</b>



## PROJECT DESCRIPTION

With a GFA of 19,606.37m<sup>2</sup>, Tiong Seng Prefab Hub is a 5-Storey Single-user general industrial building (Precast Factory) with Ancillary Concrete Batching Plant and Temporary Worker's Dormitory.

## COST IMPLICATIONS

The cost of the Cobiax cage modules was offset by direct and indirect savings. Direct savings were derived from the reduced usage of concrete and re-bars. This ultimately led to the indirect benefits of the whole building structure, such as smaller beams, thinner vertical supports due to the use of high strength concrete and a stronger foundation system.

## LOW CONCRETE USAGE INDEX

With the aim of reducing the building's CUI, precast components and Cobiax system were employed in this project to reduce 676.55m<sup>3</sup> of concrete which also indirectly reduced the carbon emission by 142.075 tonnes of CO<sup>2</sup>. This involved the use of 275mm thick precast cobiax slabs with grade 35 concrete. A slab design incorporating 140mm voids was used, as compared to 200mm solid slab in the original design. The load reduction was 2,046.59kN which was 35% lighter than the solid flat slab. Moreover, all the non-structural structure elements such as internal drains, pavement and road kerbs used recycled concrete.

In addition, there had been extensive use of precast technology not only in the structural but also in architectural elements as well such as beams, columns, walls, slabs and RC ledge had been prefabricated in precast yard and installation done on site. With these precast elements, lesser plastering was required as they have better finishing in off-form concrete finish.

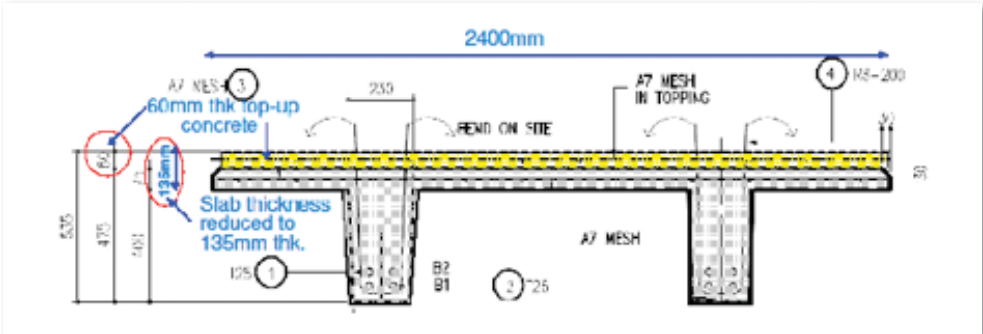
## SUPPLIERS' CONTACT

**PRECAST ELEMENT SUPPLIER :**  
**ROBIN VILLAGE DEVELOPMENT PTE LTD**  
 63 Tuas South Avenue 1  
 Singapore 637282

**COBIAX SYSTEM :**  
**COBIAX TECHNOLOGIES (ASIA) PTE LTD**  
 510 Thomson Road #08-00  
 SLF Building Singapore 298135

(PRECAST) DOUBLE T-SLAB SECTION

2400mm W x 8570mm L x 135mm thk



PANEL WEIGHT	7.00 TON
CONCRETE VOLUME	2.90 m <sup>3</sup>
CONCRETE GRADE	C35

Fig.21

DOUBLE T-SLAB SECTION  
USED IN PREFAB HUB

(Original design of all the conventional slab is 200mm in thickness)



**Pic.34** POSITIONING OF COBIAX S-140 ON A STEEL PALLET



**Pic.35** COBIAX HALF PRECAST SLAB AFTER PLACING ON THE BEAMS AND READY TO RECEIVE CONCRETE TOPPING UP



**Pic.36** DOUBLE T-SLAB PRECAST BEING HOISTED UP FOR INSTALLATION



**Pic.37** DOUBLE T-SLAB PRECAST BEING PLACED ONTO THE BEAM AND READY FOR REBARS INSTALLATIONS READY TO RECEIVE CONCRETE TOPPING UP



**Pic.38** DOUBLE T-SLAB PRECAST REBARS INSTALLATIONS AND READY TO RECEIVE CONCRETE TOPPING UP



**Pic.39** DOUBLE T-SLAB PRECAST INSTALLATION COMPLETED

## EDUCATION RESOURCES CENTRE AT UNIVERSITY TOWN (NATIONAL UNIVERSITY OF SINGAPORE)



**Pic.40** ERC @ NUS

### PROJECT TEAM

Developer:	National University of Singapore
Architect:	W Architects Pte Ltd
Structural Consultant:	T. Y. Lin International Pte Ltd
M&E Consultant:	Parsons Brinckerhoff Pte Ltd
Contractor:	Kim Seng Heng Engineering Construction (Pte) Ltd
TOP Date:	24th May 2011
CSC Date:	21st September 2011

Concrete Usage Index: 0.47  
Buildability Score: 71  
Green Mark Award obtained: Platinum

## PROJECT DESCRIPTION

The Education Resource Centre located at the town green of NUS University Town consists of four-storey free-formed layouts, central courtyard with conserved matured trees and an auditorium. The project with total construction floor area of 21,910m<sup>2</sup> received the BCA Green Mark Platinum Award in 2010.

## LOW CONCRETE USAGE INDEX

The total volume of concrete used for the project was 10,318.16m<sup>3</sup> of which the structural elements consumed 9,269.5 m<sup>3</sup>.

With the aim of achieving low CUI in mind, the following structural schemes of typical floor system were studied at the project preliminary design stage, as shown in figures 22-25:

- Reinforced concrete flat slab with or with drop panels
- Post-tensioned concrete flat slab with drop panels
- One way post-tensioned concrete slab and beams
- Reinforced concrete slab and steel beams

## SUPPLIERS' CONTACT

### STRUCTURAL STEEL WORK :

**HOE HOE ENGINEERING PTE LTD**

62 Woodlands Industrial Park E9

Singapore 757832

### SUN SCREEN LIGHT STEEL FRAME :

**GH ENGINEERING PTE LTD**

21 Tuas Avenue 18a

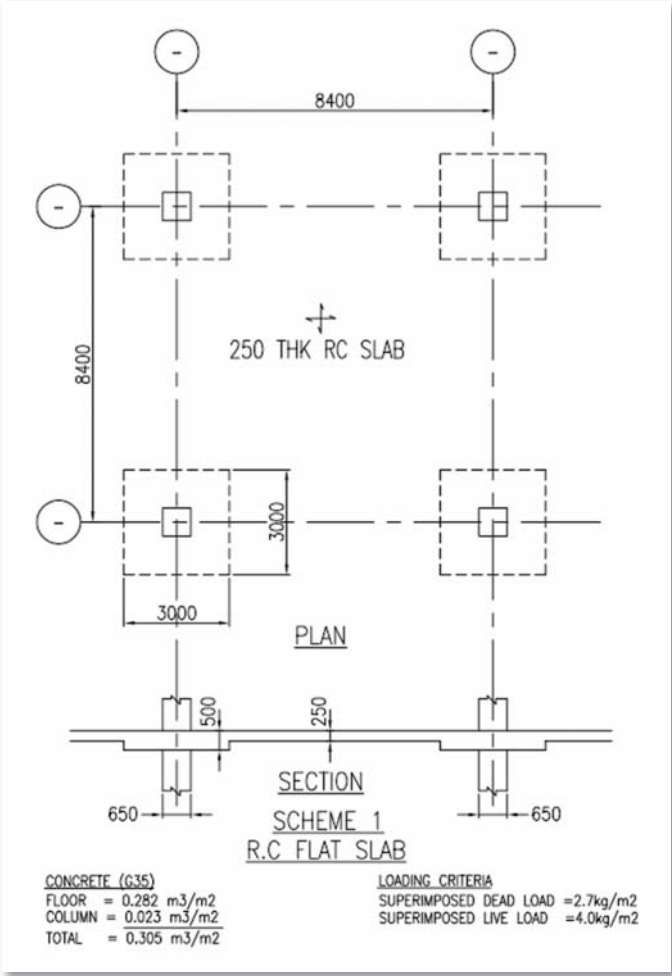
Singapore 638866

### POST-TENSIONED CONCRETE WORK :

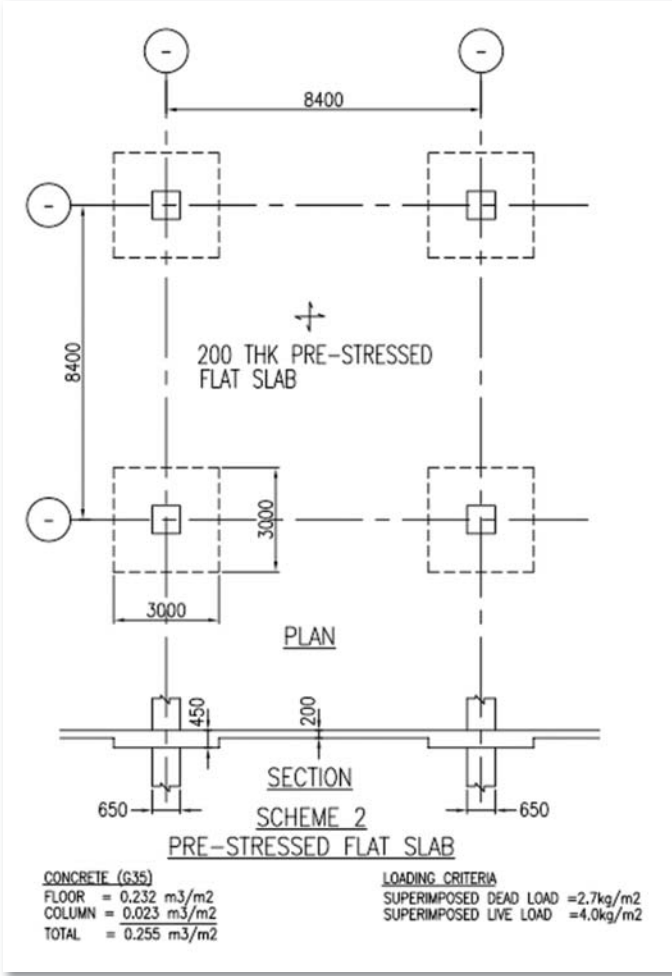
**UTRACON STRUCTURAL SYSTEMS PTE LTD**

7E Pioneer Sector 1

Singapore 628446

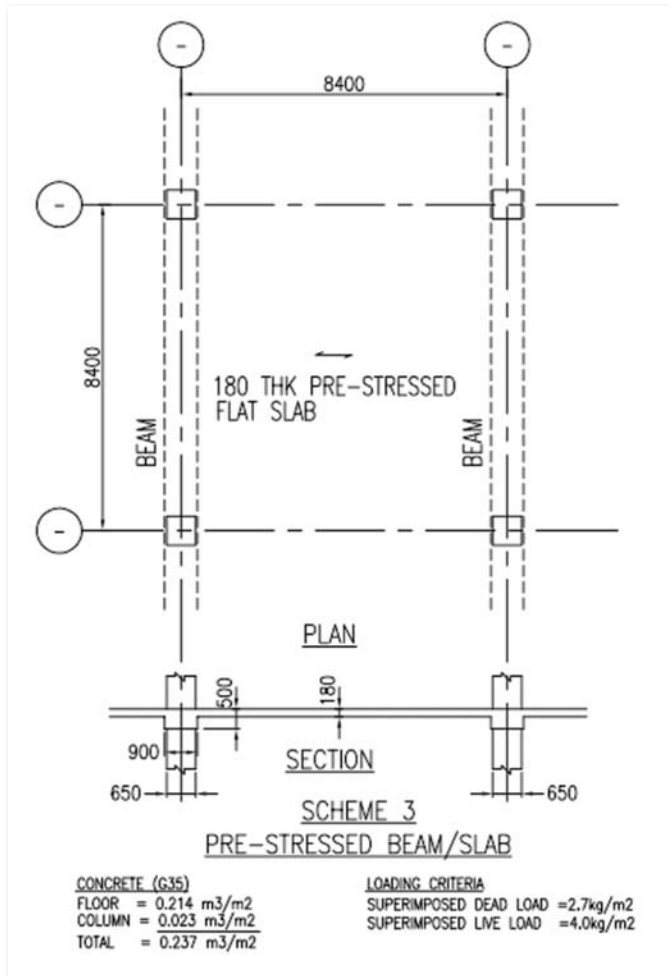


**Fig.22** SCHEME 1 : R.C. FLAT SLAB

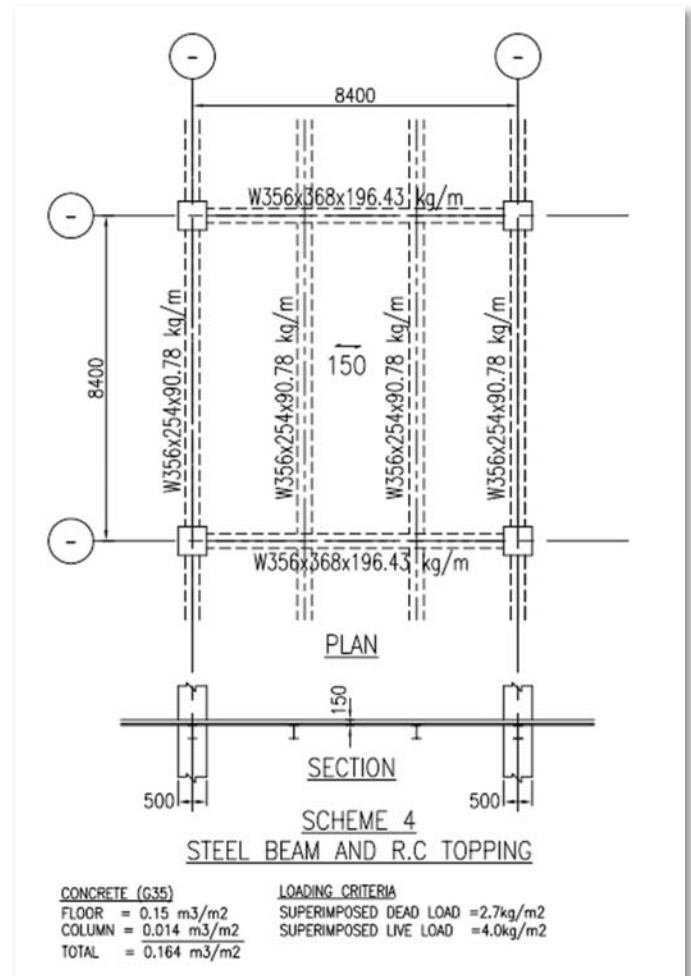


**Fig.23** SCHEME 2 : PRE-STRESSED FLAT SLAB





**Fig.24** SCHEME 3 : PRE-STRESSED BEAM-SLAB

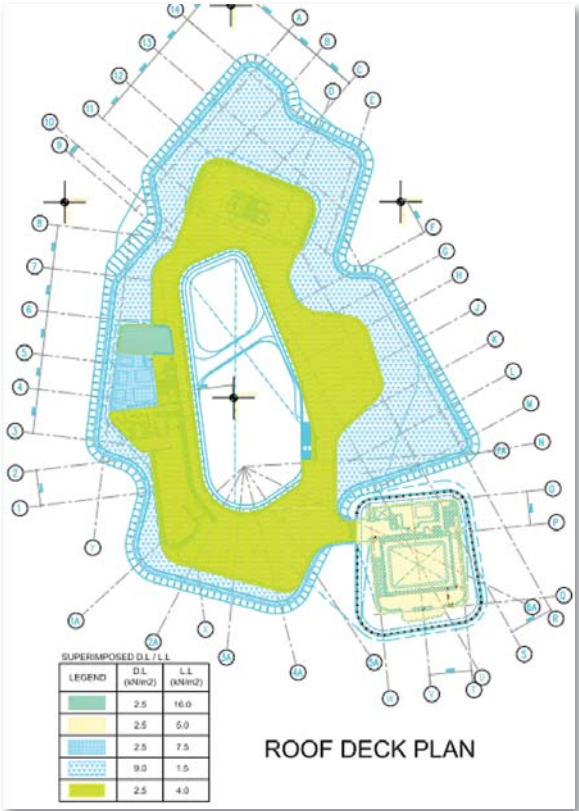


**Fig.25** SCHEME 4 : STEEL BEAM AND R.C. TOPPING

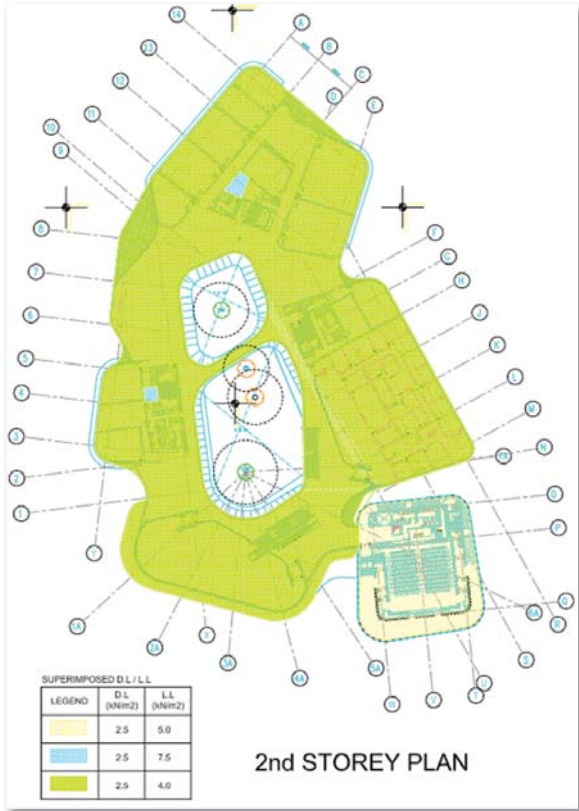
DESIGN LOADS AND STRUCTURAL SYSTEM

The final selection of the structural system took further considerations of the free-formed floor plates and configuration of the column layouts.

The design live loads of the landscaped roof and typical floor are indicated on the following floor plans, as shown in figures 26 and 27:



**Fig.26** DESIGN LIVE LOADS OF LANDSCAPED ROOF



**Fig.27** DESIGN LIVE LOADS OF TYPICAL FLOOR

In general, the structural system adopted flat slab design. Drop panels were provided for punching shear control due to the relatively small column sizes allowed in the building. Drop panels were also extended to the cantilever ends for deflection and vibration controls.

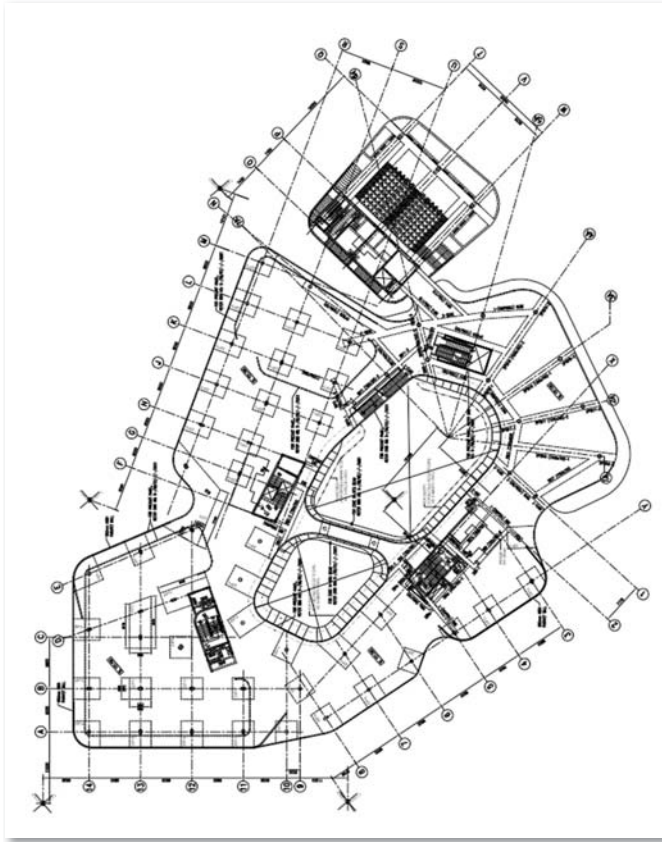


Fig.28

**PLAN SHOWING 2nd  
STOREY OF BUILDING**

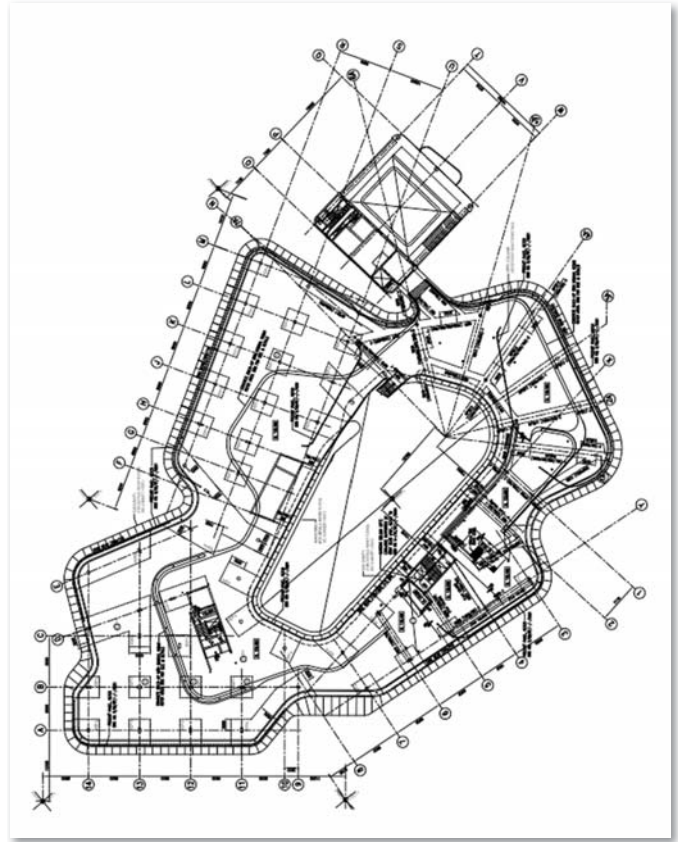


Fig.29

**PLAN OF SHOWING ROOF  
STOREY OF BUILDING**

### OTHER DESIGN CONSIDERATION

To further reduce CUI, metal roofs with steel frame were used for the auditorium structure. Light steel frames were also used for metal canopy and double tiers sunshades around the building perimeter.



**Pic.41** TOP VIEW OF ERC @ NUS



**Pic.42** SMALLER COLUMNS USED IN THE BUILDING



**Pic.43** INTERIOR VIEW OF THE BUILDING









**SECTION 05**

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# **ACKNOWLEDGEMENTS**

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- LSW CONSULTING ENGINEERS PTE LTD
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(RSP Architects Planners & Engineers (Pte) Ltd)

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