The construction of Super High-rise Composite Structures in Hong Kong

This Powerpoint presentation is prepared by

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Introduction

Quite a number of Super High-rise buildings have been built in the recent years in Hong Kong. Majority of these buildings are in the form of composite structure, that is, they are built using reinforced concrete as the core and structural steel as the outer embracing frame.
Example of Buildings constructed in composite manner

1. Single-Tower type structures
   - Manulife Tower (previous Lee Gardens Hotel)
   - Cheung Kong Center (previous Hilton Hotel)
   - International Finance Center Tower 2

2. Multi-Tower type structures
   - Shun Tak Center
   - Time Square
   - Hotel/Office towers in HKCEC Phase I

Sectional-mixed structures (Lower floors in RC/upper in composite)
   - Citic Tower
   - International Finance Center Tower 1
Redevelopment of the Lee Gardens Hotel – The Manulife Tower
Redevelopment of the Hilton Hotel – Cheung Kong Center
International Finance Center Tower 2
International Finance Center Tower 1 – RC core + RC perimeter columns configuration up to 23/F, 23/F to 38/F becomes a composite structure with columns & slabs in steel
Characteristic for buildings constructed in composite manner in Hong Kong

• Size of building usually very large – floor area ranging from 1800 to 2500 sq m, total floor area from 80000 to 200000 sq m

• Structural forms bear similarity – RC core as the inner tube provide rigidity, external frame with perimeter steel columns/edge beams, floor in composite deck with RC topping

• Very few columns provided at base/lower level to create spacious lobby at Ground entrance

• External bracing members are seldom used to avoid blocking of valuable exterior view. Belt truss and outrigger systems are used instead

• Buildings usually consist of a very large and deep basement
IFC 2 – structural configuration of the tower with the first set of Transfer/Belt Truss on 6/F, mega-columns, edge beams, floor deck, and the RC core.
Connecting the steel frame to the inner core as seen in the Cheung Kong Center
External bracing

Diagonal bracing on external wall seldom used in Hong Kong’s building. The one as seen here is the Shenzhen Shun Hing Plaza.
A 5-level basement was constructed using top-down arrangement at the same time together with the IFC2 superstructure.
Similar situation of construction a deep basement using top-down arrangement also appeared in the Cheung Kong Center project.
Major elements in Composite Building Structures

Core wall

- Serves as the major load taking element and to provide rigidity to resist deflection caused by lateral load (wind)
- Usually formed by mechanical-lifted formwork system such as climb form or jump form
- Connection provision such as anchor plate for steel beams, build-in bar couplers or starter bar box for slab, and anchor frame for outrigger, will be provided in the core wall during its construction
The Jump form being used in the construction of the core wall for the Cheung Kong Center
Manulife Tower

Forming the core wall using traditional timber formwork inside the basement levels
Climb form system for the construction of the core wall for the Manulift Tower’s superstructure
International Finance Center Tower 2

Climb form system for the construction of the core wall for the International Finance Center Tower 2
Anchor frame and connecting plate embedded in the core wall for further connection to the external steel frame
Anchor frame used in the Shun Hing Square project in Shenzhen
Starter bar box

Connecting plate for steel floor beams

Work deck of the Climb-form system

Connection arrangement provided in the core wall
Another view of the connection arrangement at the core wall corner
Major elements in Composite Building Structures

Structural steel external frame

- Composing of steel columns that tied onto the core wall by steel beams
- Steel columns can be
  - in the form of H-section, square, rectangular or circular section
  - in-fill with lightweight concrete to increase rigidity and fire resistance
  - in the form of composite with reinforcing steel bars encased with load-taking reinforced concrete
  - in the form of concrete-filled column design
Concrete filled steel column used in Cheung Kong Center
Inlet for concrete infill

Square sectioned columns
Various forms of composite columns
Composite column comprising of thick fabricated steel section and encased with reinforced concrete.
Composite columns forming the mega-column for the IFC2
Composite column composing of H-section sub-stanchion
External steel column being erected & tied back onto core wall by steel beams
Beams weld or bolt-connected onto the gusset plate anchored firmly into the anchor plate/frame within the core wall.

Connecting steel beams onto the core wall.
Major elements in Composite Building Structures

Floor plate

- Usually in the form of RC topping composite to steel beams by shear studs
- GI corrugated decking used as permanent form for the placing of the RC topping
- Floor plate is connected to the core wall by starter bars embedded in the core wall
Placing the steel deck onto the steel beams
Detail of the slab (before concreting) with steel bars and shear stud to allow the forming of a firm composite with the beams
Connecting composite slab with the core wall and the column using starter bars.
Welding the shear stud onto the steel joist to enable the floor slab to form firm composite with the beams
Placing concrete to form the RC topping of the composite slab
Major elements in Composite Building Structures

Transfer truss

• Common design in Hong Kong to provide a spacious ground lobby to a building by using the minimum number of columns at the lower floors to support the entire superstructure

• Transfer truss is used to transfer the building loads from the upper columns down onto the main columns at lower level

• Transfer truss sometimes connected to the outrigger to increase the rigidity of the building at lower levels
The arrangement of the Transfer Truss for the Manulife Tower
Detail of the Transfer Truss located at
3/F-4/F for the Cheung Kong Center
Erecting the transfer truss system – temporary support frame to be provided for installing the large-section truss members
Elevation and Installation Arrangement for the Transfer Truss of Cheung Kong Center
Transfer Truss located at 6/F-8/F for the International Finance Center Tower 2
Construction zone for core wall

Core wall and building frame lapping zone

Building frame erection zone

6/F-8/F Transfer Truss

Overall structural/construction arrangement of the IFC 2
Major elements in Composite Building Structures

Belt truss and Outrigger

• Provided to building frame at interval every 20 to 25 floors to allow building to regain its stiffness.

• Often in the form of inclined bracing, stretching inward, outward or in “X” or “Y” configuration

• An anchor frame is embedded in the core for connecting the outrigger in order to cater for the strong pulling out tendency
Belt truss and outrigger systems of Cheung Kong Center
Layout detail of the belt truss and outrigger systems of Cheung Kong Center
Outrigger and the column connection detail
Overview of the belt truss system

Cheung Kong Center
Installation of the belt truss at carefully arranged sequence
Elevation detail of the completed outrigger and belt truss system
Installation of the belt truss

International Finance Center 2
Corner steel post embedded in the core wall

Outrigger

Composite column

The outrigger connecting into the core wall in IFC 2
Installing the bracing frame for the outrigger using a retro-installation process – core wall cast in 2 phases with the bracing frame installed in between
Corner steel post embedded in the core wall

Embedding the anchor frame into the core wall
Sequential detail of the retro-installation process of casting the bracing frame into the core wall.
Connection detail of the outrigger and the mega-column – a devices to control differential shortening between the steel column and the RC core wall is introduced
Detail of the column shortening control devices with the use of shimming pack adjusted by hydraulic action
Similar column shortening control devices was also provided in the Cheung Kong Center’s design.
Production concerns for the construction of composite structure

The construction of composite structures in Hong Kong is very complicated in terms of their size and work nature. The followings are some of the common problems often encountered.

1. Site layout to cater for very congested site environment
2. Simultaneous works
3. Cranage requirements
4. Provision of temporary work arrangement during construction
5. Height and headroom problems
6. Works at peak period
7. Controlling of rain water during construction
Extremely complicated site layout during the construction – demolition of the old basement, foundation works, forming of the building core, erection of steel column and constructing the ground slab worked almost at the same time

Lee Garden Hotel redevelopment
Layout situation during the later stage of basement formation period
Layout situation during the ground slab formation and core wall construction period
Layout situation during the construction period for the superstructure and the top-down basement
Foundation for Hotel block and basement access arrangement had just commenced

Podium and basement below was partially completed

Construction of the superstructure up to the typical cycle

Layout arrangement for the IFC2 at its peak
Layout as shown 4 months later
Working and handling of material at height
Core wall and steel frame worked at different phases – A lapse of sometimes more than 10 floors make access to the deck level of the core wall very difficult.
Temporary access provision inside the core wall
Delivery and lifting of steel members
Handling of very heavy fabricated components
Provision of lifting equipment for the hoisting of heavy steel members as seen in “The Center” and “Manulife Tower” projects
Cranage provision in Cheung Kong Center – 2 luffing cranes with 600Tm capacity was provided at corner position of the core wall
Locating the cranes inside the core wall
Cranage demand

There are altogether about 26000 steel members (average about 0.9 ton) being used in the Cheung Kong Center.

The construction period for the building frame takes about 50 weeks. That means, the cranage requirement at average is about 520 ton/week, or about 100 ton/day, excluding the lifting of other materials such as the decking sheet or usual reinforcing bars.
Temporary work provision –
Erection of a temporary steel truss for the erection of very heavy or large span elements
Erection of temporary scaffold to carry out welding works (to the outrigger system of IFC 2)
Erection of temporary suspended platform for the final installation of the overhanging steel components
Temporary work arrangement – Formation of a slot opening in the structure for the access of large and heavy components
Intensive use of dry wall making water-tightness become more crucial in composite buildings
Fire Resisting treatment to steel in composite/structural steel buildings

These can be done either by

• Encasing the structural steel elements with concrete
• Covering the elements with fire resisting boarding (e.g. cement board)
• Covering the element with fire resisting plaster (e.g. spray-on vermiculite/cement-base plaster)
Applying spray-on fire resisting plaster to exposed structural steel members
Gate valve for the infilling of light weight concrete to steel column (a way to improve performance of the column under fire)

Outrigger frame in Cheung Kong Center after the application of fire resisting plaster material
Encasing the fire escape and lift shaft with fire resisting board/partition
Encasing the steel beams with concrete for fire resisting purpose
Concrete encasement to steel members

Concrete encasement is provided to steel column in order to:

• Convert steel column into composite column
• Increase the rigidity of the column
• Make the column fire resisting
Steel column before encased with reinforced concrete
Encasing a column using traditional manual/timber formwork
Encasing a column using steel gang formwork
Encasing a column using self-climbing formwork
Operation of the self-climbing form for the composite column in IFC2
Future development of using structural steel or composite structures in Hong Kong

Instead of building very large and complex building using composite manner, which resulted to very high cost in construction, the following ways may be adopted in order to achieve more cost effective application of technology in future.

1. Use more simple and straightforward design like regular steel frame structure in grid layout

2. Use more standardized components such as universal sections, lattice trusses or prefabricated standard sections in the design

3. Apply more to other types of building structure/construction as in many developed country like Japan, USA, or even Korea and Taiwan

4. Forming hybrid structure with other prefabricated elements
The use of standard structural steel members in construction
Convenient products in market allowing the use of very cheap and effective ready-install structural steel members to form various building systems.
A hybrid structure in Melbourne, Australia with the mixed use of Precast concrete, cast-in-situ concrete and steel composite
Detail of the hybrid elements
End of this presentation