1 A GENERAL REVIEW OF THE STRUCTURAL FORM OF COMPOSITE BUILDINGS IN HONG KONG

There are not more than 10 super high-rise composite buildings being built for the past decades in Hong Kong, of which, 3 are of single-tower type (Manulife Tower, Cheung Kong Center and International Finance Center Tower 2), 2 are of multi-tower type (Shun Tak Center, office and hotel blocks for the Hong Kong Convention and Exhibition Center), 1 is of linear block type (Time Square). There are also a few composite structures which consisted portion of the building at lower floors constructed in reinforced concrete, while the upper structure being constructed in RC and structural steel composite (Citic Tower and International Finance Center Tower 1).

Buildings constructed in composite manner in Hong Kong are all very big in size. As a general reference, the building size of these buildings ranging from about 1800 to 2500 m² per floor with a total building area from 80000 to 200,000 m². There is no building example of significance smaller than the figure as quoted above being built in Hong Kong. All these structures bear a number of commonality in their structural form. Due to the height of the building and the tremendous wind load they are taking, these structures are all founded either on large diameter bored piles or directly seated on bed rock (photo 1). They all have a deep basement, for some cases reaching almost 30m down into the ground. A RC core wall which is usually located in the center part of the building and serves to provide the rigidity to the entire building, is also a typical design. Other stiffening provisions used in the design include the transfer truss, belt truss and outrigger systems. However, large-sized bracing members on the external frame are seldom used due to the blocking of the valuable exterior views. Some other forms of composite design, such as the use of Steel/RC composite column or concrete-filled steel column, are sometimes used as a further means to increase strength and rigidity of building. For floor structure, steel beams with RC topping is again a typical design.

Please refer to photo 2 - 5 for general views of some of the quoted projects.
the core wall ranges from 400 to 900m², and sometimes with a thickness close to 2m at its base. Inner walls cast at the same time with the main walls are also provided as a means to increase sectional stiffness. These load bearing walls serve mainly as FR partitions for the lift or stair shafts or other servicing purposes.

Mechanical-lifted formwork systems, like the climb-form or the jump-form systems (photo 6), are employed for the construction of the core wall. This formwork system usually can achieve a working cycle of 4 to 5-day per floor comfortably. Since the form can only cast the vertical wall elements, while the floor slabs, both inside and outside the core, are required to construct at a later stage. Due to the delay caused by other operations (such as the installation of the outrigger system), sometimes a lapse in the work phases with more than 10 floors between the core and the working floor structure is not uncommonly (photo 7). Therefore, special access and safety arrangement to allow workers making access to the working level at the top of the core wall have to be provided.

Connection provisions such as anchor plate for steel beams, build-in bar couplers or starter bars for floor slab, or even an anchoring frame for the connection of the entire outrigger structure, are required to embed in the core wall during the casting process (photo 8 and 9).
Photo 7. A lapse of 12 floors between core wall and steel frame due to delay by the erection of the outrigger

Photo 8. Anchor frame embedded in the core wall and cast in an in-situ manner

Photo 9. Anchor frame formed in a retro-installation manner (core wall cast in two phases with the anchor frame installed in-between)

2.2 Structural steel external frame

The external frame mainly comprises of the steel columns which is usually located at the building perimeter and steel beams that tie the columns onto the core wall. Steel column can be in the form of H-section, square, rectangular or circular section, sometimes infill or encased with structural concrete to improve rigidity as well as fire resistance (photo 9a). For Hong Kong’s super high-rise buildings, these columns can be as large as 3m x 3m in size, with a steel section up to 2m² (photo 10 and 11).

In order to cater for the differential shortening occurs between the RC core wall and the steel columns, adjustment devices (using packing shims) is sometimes provided in columns so that the observable shortening can be toned by hydraulic action (photo 12).

To make use of standard sections as much as possible, floor beams are often designed in standard I-section, with span ranging from 8 to 14m (photo 12a). Small-section lattice truss is seldom used due to their insufficiency in strength. Edging beams of larger section are often required to improve the rigidity of the columns. Connection of the beams to the core wall is made by cleats and further connected onto the built-in anchor plate by welding.

Photo 9a. Concrete filled column used in the Cheung Kong Center project

2.3 Floor plate

Floor plate is in the form of reinforced concrete topping composite to the steel beams by shear studs. In most cases, corrugated galvanized iron decking is used as a permanent form which placed on top of the beams for forming the slab (photo 13). The floor plate is further connected to the core wall by starter bars which are already embedded in the wall. Thickness of the slab is around 180 to 200mm which forms a very strong lateral restrain to provide additional stiffness to the entire building structure.

Photo 10 and 11. 2.5m x 2.5m column fabricated from 150mm thick steel plate for the Manulife project (left) and the Mega columns in IFC Tower 2 with averaged weight of steel at 9.7ton/m
2.4 Transfer Truss

This is a common design used in Hong Kong, the purpose of which is to provide a roomy and spacious ground entrance to a building. Usually very few numbers of columns, sometimes 2 on a side of a building, are provided at the entrance level. While above the entrance, normal configuration with closer columns is resumed. The transfer truss system is thus used to transfer the building loads carried from the upper columns down onto the main columns (sometimes called the super or mega columns). This structure is often in the form of a very huge truss that has a height equivalent to 2 to 3 normal floors (photo 14 and 15). In some cases, the transfer truss is also connected to the outriggers, which serves to tie the external frame onto the core wall and provide the rigidity required on the lower section of the building.

2.5 Belt truss and outrigger

They are provided to the building frame at interval every 20 to 25 floors to allow the building to regain its stiffness after a significant drop occurs in typical floors. Again, the belt truss and outrigger system is a very huge structure and stretches 2 to 3 floors in height, which involve amount of steel sometimes as much as 10 times that is required for equivalent typical floors (photo 16a, b and c).

Outrigger is often in the form of inclined bracings, which tilts outward, inward, or in
both directions forming a cross or Y-shaped brace frame (photo 17). Occasionally, it can be replaced by large-sectioned beams in order to reduce the obstruction caused by the braces. Due to the very strong pulling out tendency, the outriggers are connected by welding to the anchor frame which is embedded inside the core (photo 18a and b).

2.6 Other structures inside the core wall

Minor structures inside the core such as floor slabs of the lift lobby or other utilities areas, fire resisting wall or normal partitions for services rooms or toilets, are formed at an elapsed time by manual formwork method (photo 19). However, these inner wall systems are sometimes replaced by dry walls due to the omission of wet works during the forming process (19a).
3 PRODUCTION CONCERNS FOR THE CONSTRUCTION OF COMPOSITE STRUCTURE

The construction of large-sized composite structures is not an easy task, in particular in most cases where a gigantic and deep basement is part of these projects. The construction period usually takes more than 3 years, excluding the time for the foundation and other works in an advanced phase.

On the production side, a number of practical problems should be noted in the construction process due to the unique nature and tremendous amount of activities involved, such as:

3.1 Site layout to cater for very congested site environment

To handle activities which work simultaneously with reinforced concrete and structural steel, together with the installation of other building services and fitting out works for very large and complicated building projects in a congested site is indeed very difficult, in particular to have all these essential things being carried out in close proximity in term of time and space (photo 20 and 21). Problems like how to provide for the delivery and storage of the bulk and heavy materials, circulation and movement of materials and plants; locating the waste and environmental control equipment, administration and logistic areas; or provision of access and safety routes etc, should be catered for carefully and efficiently and to eliminate double handling as far as possible.

3.2 Simultaneous works

There are situations where a number of major construction works are constructed simultaneously with the main building structure, such as:

a) working at the same time with a basement, which is constructed usually using top-down arrangement (photo 22),
b) with a very large-sized podium structure (photo 23),
c) with other ancillary works such as pedestrian/vehicular linking structure or other external works.

These works are often very large-scale by themselves and cause significant coordination problems to the main structure in terms of scheduling, resources allocation, access to works, storage and site facilities etc.
3.3 Cranage requirements

There are countless heavy items for super high-rise composite buildings. These items come from 3 main activities, such as reinforcement bars and formwork shutters for constructing the core wall, individual or assembled structural steel members, and other plants and equipment for the building services installation. Some of these items are extremely heavy, such as in the case of THE CENTER, an assembled member for a section of the column cluster (there are more than 10 pieces of this) weighs more than 60 tons (photo 24). While the number of other smaller members is enormous, sometimes it calls for more than 50,000 pieces with average weight close to 1 ton each. For the 88-storey International Financial Center, the tower crane takes 8 minutes to make a delivery from ground level to the roof. Sufficient carnage provision will guarantee the project be completed efficiently and on time (photo 25).

3.4 Temporary works

A number of temporary works and related provisions are often required during the construction period. These works mainly are provided to facilitate the erection of some very heavy, complicate-shaped or difficultly positioned structural components such as:

a) supporting trusses (photo 26),
b) falsework for long-span components,
c) falsework for structures with very high headroom,
d) temporary work platform to store or support very heavy materials or plants (photo 27),
e) temporary pier along seawall to allow barges to unload structural steel components and members,
f) provision of slot openings in the main structure for the entrance of very big assembled components (photo 28).

These works are very costly both for the erection, dismantling or making good afterward. They also affect the critical path of the main
program and should therefore be planned very carefully in the overall building schedule.

3.5 Height and headroom problems

When talking about super high-rise buildings we refer to those with 200m or above in height. Besides human (workers) psychology and safety, quite a number of practical problems will accompany when the working position is at height. For example, the access for both human workers and materials to the upper part of the building becomes more difficult and time consuming, more access provisions or safety measures are needed when working at height, the rate of work done is getting smaller, or, there is stronger wind and more severe climatic environment when reaching higher altitude.

3.6 Works at peak period

In terms of cash flow, value of works to be completed during the peak period can be up to US$10 million per month. There may be more than 2000 workers from more than 50 trades working inside the site every day. Daily consumption of building materials can be in the region of 500 to 600 tons. How to manage all these activities orderly and have the resources arrived to the right place and on time under a coordinated manner is a great challenge in these projects.

3.7 Controlling rain water getting into building during construction period

The construction of super high-rise building practically sub-sectioned into a few logical phases. Counting from the top level working in advance is the construction of the core wall. Follows sometimes with a lapse of as much as 10 floors or more, is the erection of the structural steel building frame. Further downward with a lapse of some 15 to 20 floors starts the fixing of the curtain walls, and with other interior fittings that are catching up from below. As seen from this sequential arrangement of works, the building at the initial stage can hardly be water sealed. The exposing vertical and horizontal openings of the still incompleted upper structure are convenient access for rain water. There are examples that the installed dry wall partitions on the lower floors are being wetted after a thunderstorm. Rain water runs down from the lift shaft and services ducts from the upper level have damaged more than 40 storeys of internal dry wall below the leaking point. The replacement of the damaged walls will be costly and may delay the final completion of the project.
4 FUTURE TRENDS

The way how Hong Kong is using structural steel to construct buildings is far beyond what can be described as efficient and cost feasible for common projects. The use of structural steel or composite structure in building construction at present only limited to super high-rise or projects with exceptionally large size. The adaptation of technology that is supposed to be economical, such as the use of structural steel in construction, has not happened in Hong Kong as it is in most of the developed world.

The past decade is an important era for Hong Kong in the searching of new and cost effective technology in construction. It is, on one hand, the experience gained in the recent projects working with structural steel or composite design and construction, is significant. More and more architects, engineers, contractors and workers begin to master the skill and experience in the design and handling of this kind of construction method. They are by now feeling more confident and competent to procure a project using structural steel or composite design. What they need to do in the future is to find a way to make the work more diversify and adaptive, so that it can be able to apply to various scale and natures of projects more effectively and economically. From the view point of the author, this can be achieved by the following means.

4.1 From the design point of views, instead of using composite design, more straight-forward design like the using of simpler steel frame structure with columns and beams layout in more regular spacing and shorter span, could be adopted.

4.2 Similarly, more standardized components such as the use of universal sections, simple lattice trusses or prefabricated standard sections, could be used in order to cut cost and make installation easier and economical.

4.3 Applying the design to buildings of various types, nature and scale, such as for hotel, hospital, school, office and commercial buildings, or even for residential buildings of medium-rise nature. These are areas that structural steel can be made use of more effectively.

5 CONCLUSION

With the limited composite building cases being executed in Hong Kong, the rate of development and technology transfer is still unsatisfactory. One of the consequences is that this form of construction technique is still not be able to make use of in a more popular manner for other possible types of buildings.

At present, majority of these projects are designed by one or two leading consultant firms. Experienced contractors and operatives are also insufficient. This may discourage developers to select this construction option due to its relatively higher cost resulted from unpopularity in its application. At the same time, other related factors such as the adopting of more composite design with the use of in-situ reinforced concrete, precast elements and structural steel at the same time in a project (photo 31); the familiarization in the using of other finishing options other than solid external walls or traditional cladding systems; or the development of better and more adaptive building codes in the area of structural design or fire and safety requirements both by the engineers or the approving authorities, may also help in the technological evolution process. Otherwise, methods to construct buildings will remain traditional and cannot get advancement as the same pace with the rest of the modern world.

REFERENCE


