Construction and Performance of Curtain Wall Systems for Super Highrise Buildings

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INTRODUCTION

The construction of super highrise buildings has been very active in Hong Kong for decades. Recent renowned projects like the 50-storey Manulife Tower, the 62-storey Cheung Kong Center, the 80-storey “Center”, the 88-storey International Financial Center, and a number of recent residential buildings exceeding 60-storey tall, are without exception, using curtain wall as their external envelope.

Using thin wall as external envelope for tall buildings has always been a challenge to designers and builders, in particular in terms of cost, energy, water-tightness, installation, dimensional and structural stability, interfacing arrangement with other building components and maintenance etc. Making use of the Hong Kong’s experience, the writer wish to highlight some local practices and summarize how such thin wall systems are designed and installed.

USING CURTAIN WALL IN BUILDINGS OF HONG KONG

High-rise buildings started to spring up in the skyline of Hong Kong since the 1970’s in parallel with her economic take-off from a traditional manufacturing-based industrial economy and transforming herself into an world-renowned international financial centre. High-rise buildings by that time were concentrated in the commercial districts like Central in the Hong Kong Island and Tsim Sha Tsui on the Kowloon Peninsula side.

The first generation of buildings using what-so-called a curtain wall system can hardly be described as a full system which is usually of proprietary design. The pioneer systems were just external façade/walling designed by local architects and with materials supplied by local manufacturers. The common systems used by that time were in majority stick-type, spandrel and cover, or unit-in-frame systems, constructed of aluminum sections, sometimes incorporated with large areas of stone slabs to cover up solid walls. They were popular due to their highly adaptability, low cost, easy to design-and-install nature.
More deluxe commercial buildings were built in the late 70’s as the economy of Hong Kong growing hotter and hotter. Developers tended to request for systems with higher performance as the external envelop for their buildings, in terms both of appearance, material, construction and maintenance concerns.

Due to the relative lack of experience at that stage, the performance of these second generation curtain wall systems (from late 70’s to mid 80’s) could still hardly described as satisfactory. Problems like seepage, staining, deformation, deterioration and rapid aging of the jointing materials, were very common to many walling cases, often to a condition that made repair and maintenance almost impossible. The replacement of these walling systems not only costly, but also created great disruption to the normal utilization of the building users, and at the same time badly lowered the property value of the entire premises.

Photo 1 – Commercial centres of Hong Kong where buildings with curtain wall of various era form an excellent showcase (from left, Central in HK and Tsim Sha Tsui on the Kowloon side.

The third generation of curtain wall systems roughly started in the mid/late 80’s, by the time Hong Kong was experiencing her economic climax before the handing over of her sovereignty back to China in 1997. Accommodated experience in the application of curtain wall systems in high-performance buildings contributed solidly in the process of perfecting these systems. Throughout the period, the design and production teams, as well as the manufacturers and the engineering supporting teams, were growing more mature in the mastering of the local situation and market. Most problems appeared in the previous cases have been much effectively taken care of. Systems of this generation are in general much more satisfactorily received by most users.

WHAT IS A CURTAIN WALL

Metal and glass curtain wall systems have found growing favour in modern architecture. They are easily distinguished from other types of claddings by their thin mullions of horizontal and vertical metallic bars surrounding an all glass or metal panel. The curtain wall system has
evolved rapidly over the last two decades, especially with respect to weather control performance. The early systems presented frequent rain penetration problems; water stain patches would form on the outside or condensation on the inside mullion surfaces; glazing seals were sometimes pumped out of the rabbet of sealed double glazing window units. However, most of these difficulties were eventually overcome with improved detail design of the system components. Today, most curtain wall manufacturers offer a quality product line of components which can be used to create one of the best overall exterior wall systems.

A curtain wall system is a lightweight exterior cladding which is hung on the building structure, usually from floor to floor. It can provide a variety of exterior appearances but is characterized by narrowly spaced vertical and horizontal caps with glass or metal infill panels. These systems provide a finished exterior appearance and most often a semi-finished interior as well. They are also designed to accommodate structural deflections, control wind-driven rain and air leakage, minimize the effects of solar radiation and provide for maintenance-free long term performance. Most of today’s metal curtain wall systems are constructed of lightweight aluminum or its alloys, although some may be of steel.

COMMON TYPES OF CURTAIN WALL SYSTEMS

External wall with large area of glazed portion that carries no superimposed load except wind load is usually termed as curtain wall. Traditionally curtain wall consists of a metal frame system infill with vision or opaque panels, that serves to provide glazing for window openings as well as to cover-up structures like columns, slabs and beams, or sometimes even sections of solid wall.

There are many ways to serve the purpose, depending on a number of factors such as the design and budget for the project, layout and shape of the building structure, as well as other architectural or structural requirements. According to the American Architectural Manufacturers Association, curtain wall systems can be classified in five types, namely, the stick system, unit system, unit and mullion system, panel system, and the column-cover-and-spandrel system. However, due to the introduction of high-performance framing/articulation products and high-strength structural glass, some newer forms of curtain wall systems such as large-area glazed wall using spider clips, bow mullions, hangers or cable stiffeners as supports and connections, are new systems that cannot easily be classified using traditional concepts.

Stick system

Curtain wall in stick system is a cladding and exterior wall system which is hung on the building structure from floor to floor. It is assembled from various components to include steel or aluminum anchors, mullions (vertical load taking member), rails vision glass, spandrel panels, insulation and metal backing pans. For the fixing of the system, there are various hardware components such as anchors, connectors, brackets, cramps, setting blocks, corner blocks, gaskets and sealants etc.
This system has the following merits/demerits:

**Merits**
- Low cost, components can be made in standard design and stocked as proprietary product for use in bulk quantity.
- Shorter time for design and fabrication.
- Fairly easy to fit the shape and form of a building.
- Require relatively simple sections to form the mullions and the backing frame.
- The design of the infilling panels can be very flexible and form various combination using different materials to provide the appearance or fulfill other functional requirements.
- With the provision of the spandrel panel (the opaque portion) in the design, more colour or design options can be achieved.
- Installation of the system only requires simple tool like a manually operated pulley set-up.
- Easier to carry out replacement, alteration and maintenance.

**Demerits**
- System is designed on a job-by-job basis
- More labour-intensive in the fixing and installation process
- Higher risk of leaking due to the existence of large amount of in-situ joints between mullion and panels.
- Involvement of large number of framing members coming from the mullion, transom or other framing parts that make the fixing at spot quite troublesome and inconsistent.
- Less fashionable for the design limited basically to monotonous grid without the elegance that other systems may achieve.
Unit System

Unit systems are composed of modulated panels that are fabricated in factory and delivered to site in one-piece for installation. The panels are fully provided with all the glazing and/or the spandrel panels, incorporated with the required insulation and other architectural features, thus requiring very limited second-fixed installation works on site. The panels are usually spanned in a floor-to-floor arrangement and may be designed in a number of standard/optional panels such as fully glazed, glazed with opaque panels, fully opaque in metal or stone slab, louvered panels, or other special modules like the corner or bayed units. In order to get the best benefit of using this system, units are often produced to an optimistic large size so as to minimize the number of units used.

This system has the following merits/demerits:

Merits
- Easy to install merely by securing the modulated panels onto the building exterior using fixing/connection devices which are usually very dimensionally flexible.
- Saving up a lot of manpower due to ease of installation.
- Higher performance units can be produced to meet stringent requirements due to better control under factory environment.
- Preferably to be used in buildings with large walling area for the economy of scale in production as well as the elimination of countless assembly of minor components on site.
Demerits
- It takes longer lead time to carry out the coordination, design and fabrication of the system/units.
- Require higher dimensional accuracy in the building structure for the fixing of the units.
- Lifting appliances may be required to assist the hoisting and installation of the large-sized walling units
- Difficult to carry out replacement or maintenance due to the interlocking nature of the modulated units.

Photo 3 – Projects using unit system curtain wall. From the left, Cheung Kong Center (62-storey), The Center (80-storey) and the Manual Life Tower (50-storey)

Unit and mullion system

This is a combination of the stick system and the unit system and may be regarded as a compromise of the two. It is more suitable for use in medium-sized projects so as to balance the factors of lead time, ease of installation and economy of scale.

Panel system

A panel curtain wall system is similar to a unit system, the difference being that a panel system has homogeneous sheet or cast panel with few joints and may not have separate mullions. Unit systems are made up of smaller components fabricated together to form much complex panels that capable to perform heavier duties or other more specific requirements. However, due to the relative simplicity of the system, curtain wall of panel system design may not be able to fulfill the usual requirements most high-rise buildings required under Hong Kong’s environment. Its use is therefore more limited to certain kinds of buildings like those of standardized design for
low-income classes or for buildings of industrial purposes. In this case, the panels can be constructed of sheet materials and manufactured in large quantity in very low cost.

**Column-cover-and-spandrel system**

Column-cover-and-spandrel system consists of column covers, which are usually made of alloyed aluminum, metal sheet or other laminated/fibre-reinforced sheet, and with glazing components and spandrel panels that fit between them. It resembles certain similarity to a unit-and-mullion system except that the structure of the building is exemplified by the column covers.

With the exception of the stick system and the unit system, other curtain wall systems are seldom used in Hong Kong.

**Structural glazing system**

The merit of using structural glazing system as external wall is to minimize the unglazed elements as much as possible, leaving glass panel almost as the only glazed surface on the wall. This can be done by providing larger mullion supports which span outward away from the structural floor of a building. Special clamping devices such as a spider bracket can be used to hold the glazing panel in position. Structural sealant is used to seal up the gap between the glazing panels.

![Detail of a glazing wall system](image1)

![A spider bracket](image2)
DESIGN PRINCIPLES FOR EXTERNAL WALL

A building enclosure may be broadly defined as a set of interconnecting elements which separate the outside from the inside. These elements would include exterior walls, a roof, other components such as windows and doors, and sometimes exposed floors. The function of a building enclosure is to control the penetration of snow, wind, rain and sun to the inside and to contain the desired indoor climate. The enclosure must meet many individual requirements but for the purpose of this paper they are limited to the following six:

- control of air flow,
- control of heat flow,
- control over the entry of rain and snow,
- control of sunlight and other forms of radiant energy,
- control of water vapour diffusion,
- accommodation of building movements.

The requirement for air tightness and consequently air leakage control is met by most curtain wall systems because the air barrier of the wall is inherent in the structural properties of glass and aluminum or steel tubes that comprise the system. The continuity of the air barrier (Figure 1)
is achieved by the continuity of the glass panel through the air seal at the shoulder flanges of the tubular mullion, and through the aluminum section to the other flange surface. The air seal between the lower shoulder flange of the curtain wall mullion and the metal pan of the spandrel panel provides continuity of air tightness to the air barrier metal pan and on to the next mullion connection. Such assemblies are regularly tested using air pressure to determine the structural properties of the glass, metal, and seals and to determine the equivalent leakage area (ELA) that remains. In addition, the Architectural Aluminium Manufacturers Association imposes upon its members many other requirements including a specification that the system must not leak more than .30 L/s per m2 of wall at a pressure difference equivalent to a 40 km/h wind.

![Figure 1](image)

**Thermal Insulation (Control of heat flow)**

The control of heat flow is generally achieved through the use of insulation. Although it is not apparent from the exterior, the curtain wall system uses considerable insulation usually behind spandrel glass or any opaque panels. Because of the materials used in the structure, i.e., glass and metal, which are highly conductive, the system must also contend with potential condensation on the interior surfaces. To curtail this effect, most curtain wall systems incorporate two distinct features: first, a sealed double glazed window or an insulated metal pan and second, a thermally broken mullion, usually with a PVC plastic insert and more recently, a foamed-in-place polyurethane connection. A sealed double glazed window unit can accommodate an indoor humidity up to about 35% at an outdoor temperature of -25 °C with little condensation appearing on the glass. Similarly, the thermal break in the aluminum or steel mullion ensures that the surface temperature of the structural mullion will remain well above the dew point temperature of the air for most building types, except for high humidity indoor environments such as in swimming pools or computer centers. The thermal break also ensures that the structural mullion is thermally stable, that is, not subject to extremes of expansion and contraction.
The "Rain Screen" Principle (Control of rain and snow penetration)

To control rain penetration through exterior walls the conventional approach is to seal the exterior façade of the building. However, experience has shown that it is unreasonable to expect perfect sealing of a façade; most sealing strategies require continuous attention and maintenance.

Studies of the rain penetration problem have revealed a better solution than the façade sealing approach. If the air that leaks in and through cracks and crevices of a façade during a rain storm were limited or stopped, most of the water impinging on the façade would migrate straight down the surface and little would penetrate the wall. This is the essence of the "Rain Screen" principle. If an airtight element is positioned behind a façade, the cavity formed between the exterior cladding and the airtight element may reach the same air pressure level as is exerted on the cladding surface, thus removing the force which causes air to flow through any façade opening. The "Rain Screen Wall" is therefore characterized by a cavity behind the exterior surface that is connected to the exterior but sealed tightly, or as tightly as reasonably possible, to the interior. The inner surface of the chamber is usually referred to as the air barrier of the wall.

In most curtain wall systems the joint between the infill panel (i.e., window or spandrel panel) and the structural mullion is usually designed to be part of a rain screen system (Figure 2). It comprises a pressure-equalized cavity, connected to the exterior by the drain holes in the exterior caps, and a pressure equalized rain deflector seal between the outside surface of the glass and the mullion cap. The chamber portion of the cavity is composed of the air seals connecting the inside face of the window glass and the spandrel panel metal pan, to the shoulder flanges of the structural mullion and other parts of the structural section. Thus the set of elements comprising the window glass, the air seals, and the aluminum section and metal pan perform the air barrier function for this wall assembly. This design configuration for curtain wall sections has proven successful and has become widely accepted.

Figure 2 & 3
Solar Radiation (Control of sunlight and other forms of radiant energy)

Solar radiation falling on building surfaces may have two distinct effects: the first is to cause a significant change in temperature of the façade elements and the second is the slow but destructive effect of ultraviolet radiation impinging on all materials, particularly organic. On curtain wall systems the most important concerns with solar radiation have been the thermal expansion and contraction of curtain wall components, in particular those forming the outside cladding, and the effects of solar radiation on the glazing elements. A warping of glass occurs due to differences in temperature between the inner and outer panes, while pumping results from expansion and contraction of the air in the cavity of the sealed units. Daily and seasonal temperature differences can also cause this effect. The action of the window (thermal pumping) is particularly stressing to the inner air seal; however, serrated edges or recessed flanges keep the seals from pumping out. Most of the ultraviolet-sensitive materials in curtain wall systems are located in the pocket and cavity areas of the joints and are partly shaded by metallic and glass components.

The Vapour Barrier (Control of water vapour diffusion)

Water in its gaseous phase (water vapour or humidity) always tries to migrate from a region of high water vapour pressure to a region of lower pressure. The migration of water vapour through a wall can be compared to heat flow; it moves through all materials at a rate that is dependent on both the resistance of the materials to water vapour flow and the difference in water vapour pressure on both sides of the material.

The migration of water vapour through an assembly of materials is not a serious problem in itself, provided it does not condense to liquid form in the material or wall. If water vapour is likely to condense in a wall, the principal defense is to restrain its migration by using, a "vapour barrier" with a high water vapour flow resistance, positioned on the warm side of the insulation material or wall assembly.

The migration of water vapour through a curtain wall assembly is checked by the vapour barrier qualities of the glass and aluminum, as these materials have near perfect vapour flow resistance for all practical purposes. Thus the inner pane of the sealed double glazed unit and the aluminum or steel inside surfaces of the mullion provide the necessary water vapour diffusion control. Sealants also contribute to the continuity of the vapour barrier.

Joints and Tolerances (Accommodation of building movements)

Movements of the structural elements of a building must be determined prior to the design of an exterior wall system. Movements may be grouped into three types:

live load deflections due to occupancy loads or peak wind loads on the building façade, and dead load deflections of the building structure, expansion and contraction of materials as a result of
temperature, radiation and sometimes hygroscopic loading, slow but inexorable movements due to gradual deformation, such as creep in concrete, foundation settlement, etc.

Although not a frequent cause of failure, building movements are not adequately considered in the design and construction of façades. Masonry that has cracked or bulged, metal siding that has sheared its fasteners or buckled, or caulking that is completely squeezed out or broken are some of the effects of building movement.

With curtain wall systems, the basic element which must be accommodated is the glass panel. Around it, the typical curtain wall system of structural tubes, pressure plates and caps allows for a differential movement of about 4 to 5 mm on a floor to floor basis and between each vertical riser. This tolerance will accommodate most building movement resulting in compression, expansion and parallelograming of the frames. If the curtain wall system must accommodate a potentially greater movement than above, it is likely that another system of mullion extrusions will be required. This inevitably leads to more complex detailing and usually a disproportionate increase in the system cost.

**STRUCTURAL REQUIREMENTS OF CURTAIN WALL SYSTEMS PARTICULARLY UNDER HONG KONG’S SITUATION**

Being the external skin and serves as part of a building structure, curtain wall should be able to fulfill a number of requirements, some of which may be very stringent, especially for complex and super high-rise buildings under the environment of Hong Kong. The followings are some common situations that buildings in Hong Kong are expected to face:

- Very large-sized building, with external walls sometimes up to 50,000m², fully cladded with curtain wall.
- Typhoons that occur during the summer season with wind speed up to 60m/s.
- Thunderstorm situation with rainfall up to 150mm/hour occasionally.
- Extreme of temperature difference with surface temperature more than 60°C under tropical sun in summer.
- Constant exposure to salty and polluted air.
- Require air-conditioning for cooling for more than 8 months a year.

In order to cater such special/local requirements, curtain wall systems suitable for use in Hong Kong should meet the following functional requirements.
Strength and stability

Besides taking up its own weight, curtain wall must be able to resist wind forces and transmitting them reliably to the building structure. Wind loads increase in severity to the height of the building. Members of the walling frames and their fixings must be strong and durable enough for the purpose. The following considerations should be noted during the design of the wall system and its support:

- Avoid too clumsy and complicated design for the ease of construction and maintenance.
- Anchorage and connection provision to the structure should be sufficiently provided using appropriate devices and methods that serve the need of a particular system.
- Walling units should be strong enough to take up positive and negative wind pressure, or avoid damage so caused due to deflection or distortion under expected building movements, and the subsequent building up of undesirable stresses to the units or their glazing.
- The members of the frame and their fixing should be made of strong and corrosion-resisting material, with appropriate design to allow expansion due to various kinds of movement.

Weather resistance

Weather resistance to a curtain wall system refers to its ability to keep out water and wind. In principle the weather tightness of curtain wall can be achieved by the use of impervious infilling or paneling materials such as glass, metal, plastic sheet or stone slab. However, joints between the materials as well as their fixing to the other contacting components often cause failures in the keeping out of weather. Appropriately designed jointing or sealing provision can improve or overcome the situation; yet the natural aging, deformation, constant movement due to wind or thermal effect, or gradual deterioration of the joints in a long run can still reduce the ability of the walling against weather. Severe environmental conditions of Hong Kong in this respect form a very challenging exercise for designer and manufacturer in most cases.

Thermal insulation and condensation

Tall and large-sized buildings using curtain wall can create huge energy loss especially when air conditioning for cooling is provided. In order to minimize the loss, in addition to the use of double-glazing glass of appropriate material and design, the other non-glazed portion should also be properly insulated with thermal effective materials under the right design. According to the Building Regulation (Energy Efficiency) of Hong Kong, it requires tower-type building to maintain a maximum of 30 W/m² in the overall thermal transfer value (OTTV) in the design.
Besides meeting the OTTV targets, very humid, extreme temperature difference and providing long period of cooling, like most building environment in Hong Kong, is typical situations that easily generate condensation problems. The result of this may cause dampness to the affected walling components, and sometimes even damp the ceiling board, dry wall or window lining that located near the cold-bridging zone. There are a number of practical ways that may further exemplify such problems, such as:

- Large amount of cold-bridging locations appear in the connections and the backing frame which are usually made of conductive materials such as alloyed aluminum, galvanized or stainless steel.
- Large number of inaccessible voids between opaque panels or spandrels, or gaps between curtain wall and structural members of building, where insulation can hardly be applied.
- Inappropriately designed walling details where weep holes, ventilation or expansion provisions allow damp air to seep in under negative pressure.
- Discontinuation of the insulating materials or vapour barrier due to the overlooking in the design or imperfect workmanship during installation.
- Deformed members or aged materials damage the weather-tightness of the wall.

**Sound insulation**

Most of the high-quality deluxe type buildings in Hong Kong are situated within the congested downtown area, some even located less than a hundred meter aside super-highway. Background noise of more than 70dB is often encountering under such situations. Fortunately, most curtain wall systems of appropriate design can meet the requirement by reducing at least 25dB of air-borne sound. Some factors such as the omission of nature ventilation provision in the window, or the strong and heavy-duty design of the walling units to provide resistance to wind load, are favourable factor from the point of sound insulation under the Hong Kong’s systems. However, modern buildings may be quite noisy due to the extensive use of building services equipment like the chilling plants, pumps and networks of pipes and ducts. The introduction of discontinuity in the jointing design at the connecting points of the major framing members and by cushioning the anchorages are often proved to be quite effective in suppressing the structure-borne sound.

**Fire resistance**

Tower-type buildings using curtain wall usually do not impose specific fire resisting requirements due to enough separating distance from the relevant boundary. However, fire spread between building compartments should be provided especially between floors or units under separate occupancy. This can be ensured by the use of fire resisting construction in the non-glazing portion of the wall, and sealing all voids and gaps between such compartments by fire resisting materials.
TESTING OF CURTAIN WALL

Curtain wall systems without a history of previously accepted test will be required to undergo a safety and performance test to confirm that they will perform satisfactorily under standard requirements. The test shall be carried out on a specimen of at least one floor height and shall include various representing features of the system being used. The test usually includes the following components:

- Air infiltration
- Water penetration under static and dynamic pressure
- Structural adequacy under static and dynamic pressure
- Vertical and horizontal seismic movement
- Glass impact test
- Hinge and frame test

Sometimes in-situ tests may also be required such as the Pull-out test to ensure the performance of the fixing connections, or water test to ensure the water-tightness of larger area of wall section.

THE INSTALLATION PROCESS

This paper will not discuss the manufacturing and fabrication of the window units. The installation process referred to in this paper covers mainly site operations such as transportation, storage and handling arrangement, first and second fix procedures and the actual installing or hanging of the components/units.

Transportation, storage and handling

Most systems used in Hong Kong are not locally made, they come mainly from Japan, USA, Germany, or sometimes from Taiwan and Mainland China. After being fabricated in factory, the walling components will be transported to Hong Kong by ship. Planning should be made carefully to arrange the shipment in appropriate batches according to the installation sequence on site to avoid missing or immaturely delivery of unwanted items that increase storage problems. All items should also be accurately marked so that the locations of use can be clearly identified.

It is more preferable to have the items hoisted to the floor position where they will be installed immediately upon delivery to avoid additional space for storage or double handling. Tower crane in most cases is used for lifting these items onto the floor position. A receiving platform (Photo 4) erected temporary on each floor should be provided to allow items to be delivered into the floor interior safely and conveniently. Special trolley sometimes may also be required for the delivery of units of awkward size or shape. (Photo 5)
Anchorage and connection provision

Building structures on which a curtain wall system is attached can be of two forms, that is, structures of reinforced concrete or of structural steel construction. And very often, in order to provide the exact form and configuration of the building, a backing frame system (Photo 6), which may be very large and complicated, will be constructed for the receiving of the walling.

Anchorage provision is required no matter which type of curtain wall system is used. For buildings in RC construction, cast-in anchor in the form of dovetail channel (Photo 7) or connecting plate (Photo 8) for the welding of hangers or cramps are usually used for the securing of the components (Photo 9). For buildings of structural steel construction, the same provisions can be welded onto the steel members directly. Dimensional flexibility to convenient installation or to allow necessary movements should be provided in the connection devices. Such flexibility can be made by the provision of slotted holes in the fixing brackets, by adjusting the position of the fixing bolts in the dovetail channels, or using teethed shimming plate between connections (Photo 10), so that alignment, level, verticality or plain of the wall can be adjusted and fine-toned.
Photo 6 – a backing frame erected on the machine floor to provide the continuity in the building exterior.

Photo 7 – a cast-in dovetail channel with the fixing bracket and a wall unit secured onto it.

Photo 8 – steel plate positioned in the floor slab for the fixing bracket to weld onto afterward.

Photo 9 – worker securing the wall unit using dimension flexible fixing/connecting devices.

Figure 9a – Fixing clamp with dimension and movement allowance
Installation arrangement

Usually lighter and smaller-sized components such as the mullion, transom, spandrel board or glazing panes are involved in stick system curtain wall, thus the installation process does not require any lifting instrument except a simple lifting rod with pulley. However, the stick system often involves a large number of components in different sections and sizes, it requires more labours for fixing and installation, and at the same time increase the inconsistence of workmanship.

The fixing and installation of unit system curtain wall can be very neat and simple. In most design, independent units with appropriate jointing provision to the adjoining units are fabricated and delivered to site for immediate installation. This is further made easy by very flexible connecting devices so that the units can almost be placed in position at one-fix and final adjusted by using the dimensional flexibility provided in the connection devices. However, the weight of the unit will require the erection of special lifting tool like a winching machine mounted on track or provision of external work gondola (Photo 10).

Owing to the structural requirements and specific nature of the backing frame, which is often constructed in structural steel, its installation usually regarded as part of the building work other than as curtain walling.

In any case, the installation is done at high level on building exterior, safety provisions such as personal protection equipment, rail and fence at building edges (Photo 11) should be provided at the work spot at all time.
Final fixing and inspection

Before the final securing of all the connections, the alignment, level, verticality and plain of the curtain wall should be checked for slight adjustment can still be made at this stage. Similarly, other details such as the position and condition of the expansion joints, edging strips, sealing or insulation materials, and other filling arrangement for the adjoining void and gaps, are to be checked to ensure they are in order before the sealing off of the walling system permanently by the finishing panels.

MAINTENANCE CONSIDERATION

Maintenance for curtain wall is a long-term consideration involving both the quality of design, control during construction and adequate maintenance throughout the life span. Once failure occurs in the curtain wall it will be very expensive to have the defects rectified and at the same time causing great disturbance to the building users. Below are some common problem sources where failures usually occur.

1. Design failure – selection and appropriateness of the system, non-compliance to design and performance standards, imperfection in the jointing design and detailing, improper use of materials etc.

2. Construction and structural failure – wrong location or method of fixing, improper anchorage and connection provision (including failure in welding), failure in the walling components, unpredicted deflection or deformation appears in the background structure, poor supervision and workmanship.

3. Aging and deterioration – discolouring and surface damaging due to weather action; corrosion due to air pollution, acid rain, or electro-chemical effect to dissimilar metals; aging and hardening of the glazing compound or sealing gasket, deteriorating of the insulating materials that lead to further dampening of the walling materials/components, disfiguring or loosening of the fixing and connections, loosening or broken-off of the glazing or other fitting items.

Curtain wall systems should be inspected regularly after they have been installed in buildings. Proper maintenance and repair are essential to keep them in a safe condition. Inspection arrangement should be made in particularly before and after typhoons. The below signs are recommended to observe closely during each inspection.

- Sign of distress and deterioration of the entire wall system,
- cracked, loose or missing glass panels,
- bulging, bowing, separation, delamination, rotation, displacement of panels,
- marks of water, staining and rust,
- damaged and missing parts, corrosion, loosening or other defects,
- extrusion, wrinkle, split, missing or other signs of deterioration of the sealing materials.
- moisture appears around or behind the curtain wall.

CONCLUSION

The application of curtain wall systems in super-highrise buildings is a big topic. Within the scope of this paper it can only cover a very little of the key issues. Having witnessed the evolution of using curtain wall in Hong Kong for the past 2 to 3 decades, a general trend, as summarized below, can be observed.

- Starting from low-cost, local-design and manufactured walling products in the early systems to the imported, deluxe, tailor-designed proprietary systems in recent years.
- Starting from simple requirements fulfilling just very basic functional needs of buildings to very specialized products or systems that can meet any stringent requirements as set by designer, engineers or environmental experts.
- The old systems were mainly stick systems due to more simple in design and production. Though labour-intensive, the relatively much cheaper labour cost at that time still made it worked acceptably. Contemporary systems are using mainly unit systems that make installation very easy and labour saving, though the design quality and coordination with other building activities are much more demanding.
- The old systems that have been used in the first and second generations often inherited with quite a lot of design imperfections and latent defects; while new systems are more reliable, some can be regarded as almost maintenance-free.

Traditional external walling methods using applied-onto products such as tile or spray-on coating are still dominating in Hong Kong. However, it is notable that the use of curtain wall is gaining its popularity quite rapidly among designers and developers due to its unreplaceable attractiveness as well as slim and fashionable appearance.

Further development and improvement in the use of curtain wall systems is an ongoing process in Hong Kong. The areas of improvement may be aiming at the development of more specific functioned, more reliable and long-life systems. Such targets may be achieved by the use of more advanced glass products, sealing compounds, gaskets or in the development of more sophisticated connecting systems; as well as the introduction of other additional functions that curtain wall may take up like the incorporation of photo-cell onto panels of wall, the providing of automatic/robotic machine in the system for external wall cleansing, or curtain wall capable to perform light show at night. Meanwhile, the continual improvement of workmanship and refinement of work detailing in particular to the areas directly in touch with the building structure or other building finishes, is a prime concern to the ensurance of a good curtain wall system, that sometimes project executives may easily overlooked.