CCTV Headquarters, Beijing, China: Services engineering design

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The CCTV Headquarters' three-dimensional layout is designed to break down the 'ghettos' that tend to form in the process of making TV programmes. The building’s ‘loop’ form encourages staff to mix, creating a better end-product more economically and efficiently.

Introduction and architectural concept

The first article in this series ¹ began with the evolution to date of this unique project. China Central Television (CCTV) has been expanding greatly, in competition with major international TV and news service providers, and so organized an international design competition early in 2002 for a new headquarters. This was won by the team of Rem Koolhaas’s OMA (Office of Metropolitan Architecture) and Arup, which subsequently allied with the East China Design Institute (ECADI) to act as the essential local design institute (LDI) for both architecture and engineering. The previous article outlined the design collaboration process.

The unusual brief, in television terms, was that all the functions for production, management, and administration would be contained on the chosen site in the new Beijing Central Business District (CBD), but not necessarily in one building. In his architectural response, however, Rem Koolhaas decided that by doing just this, it should be possible to break down the ‘ghettos’ that tend to form in a complex and compartmentalized process like making TV programmes, and create a building whose layout in three dimensions would force all those involved to mix and produce a better end-product more economically and efficiently.

The winning design for the 450 000m², 234m tall, CCTV building thus combines administration and offices, news and broadcasting, programme production and services – the entire process of Chinese TV – in a single loop of interconnected activities around the four elements of the building: the nine-storey ‘Base’, the two leaning Towers that slope at 6° in each direction, and the nine to 13-storey ‘Overhang’, suspended 36 storeys in the air (Fig 1).

The public facilities are in a second building, the Television Cultural Centre (TVCC), and both are serviced from a support building that houses major plant as well as security. The whole development will provide 550 000m² gross floor area and covers 187 000m², including a landscaped media park with external features. Work began on site in September 2004.

1. The functions and layout within the CCTV building.
CCTV briefing

CCTV's competition brief was very detailed, setting out the requirements for the organization's main departments and their relationships with each other, but on the assumption that each major grouping would be in adjoining but separate buildings. To their great credit, when CCTV chose the OMA/Arup competition entry, they completely rewrote their original brief and populated the competition building to make best use of the winning concept.

This revised brief stayed remarkably intact throughout the design, with few changes as it evolved. To have such detail at competition stage and subsequently at the commencement of design was very beneficial for the swift development of the MEP services, as CCTV had given thought to every individual space and defined its services needs. In addition, CCTV made it clear at the outset that the latest modern services hardware for the project could be sourced from within China, and this was found to be true with few exceptions.

Services provisions

Continuity of operation is essential for TV; consequently two 63MVA secure independent electrical supplies at 110kV serve the site. These operate simultaneously, sharing the load, but each can support the full site load should the other fail. A third separate 10kV special use supply is also provided. 13MVA standby generator capacity backs up the secure high voltage supplies, providing essential power for broadcasting and life safety systems in the event of catastrophic failure of all incoming supplies. Key broadcasting systems also have UPS (uninterruptible power supply). Cooling of broadcasting areas, their support rooms, and the substations that serve them is also critical for continuity. A hierarchy of cooling load shedding and circuitry gives priority to these areas.

The Beijing CBD is well provided with district heating systems as well as city steam, so there is no boiler installation on site. The district heating provides all the heating needs, and the steam system gives humidification and heating backup during district heating maintenance shutdowns.

HVAC system selection

The CCTV building

From operating experience in their existing buildings, CCTV preferred variable air volume (VAV) systems. Arup’s review of Beijing climate data indicated that there were long periods when substantial free cooling through the VAV system would be economically beneficial (Fig 2). Significant areas of the building operate continuously and others for extended evening times, enhancing the benefits of free cooling via the VAV system. The internal cooling loads in most areas were beyond the capacity of chilled ceilings and passive chilled beams, but active chilled beams and four-pipe fan coil units were possible options.

CCTV had poor experience with ceiling-mounted fan coil units: leaks, condensation, and regular maintenance of filters and fans at high level were among their concerns. Also, chilled water and condensate drains were unacceptable above ceilings or anywhere at high level, except in mechanical plantrooms, to reduce the risk of drips or leaks damaging broadcast equipment.

VAV systems with terminal reheat were agreed as the preferred option. As the structure is all steel, the ceiling voids are deep enough to accommodate large supply ring ducts, the void being a plenum return path. Long and repeated discussions were held over the amount of ‘porosity’ acceptable in the beams to allow services to pass through structure. It was a complex situation, as the sloping façade and vertical core meant that both the structural and the HVAC layouts changed every few floors, resulting in many different solutions dependent on location. Having the HVAC supply and exhaust risers inside the steel core structure also generated some interesting integrated solutions.

The TV studios vary in size from 2000m² with a large audience to less than 100m² with low occupancy. They range from the lowest basement levels up to the 50th floor, and the HVAC solutions vary with size and location. The larger studios were zoned and had dedicated air-handling plants with direct connection to outside air. Higher up the building this was not feasible, so small plantrooms were located on the floor adjacent to the studio, with ventilation air from the VAV system (Fig 3).

Having agreed the system concept, the location and size of air plant was reviewed. If floor-by-floor plantrooms were used they would have to be adjacent to the façade to use 100% outside air for free cooling. Initial assessments showed that more than 150 plants would be needed, mostly in prime usable perimeter space and requiring regular maintenance access via operational areas.
The team settled on nine main air plantrooms, with the unusual solution of several large parallel linked air-handling plants serving large vertical supply and exhaust risers in the central core (Fig 4). Each plantroom serves 10-20 floors, with supply riser velocities starting at 15m/s and exhausting at 12m/s, and lower velocities in floor ring mains and branches. A typical plant arrangement has six air-handling units (AHUs) at 25m³/sec each. As the air volume required decreases, the control system, continuously calculating the total volume, isolates an AHU and adjusts the fan speed of those remaining. Further reductions in volume allow more units to be isolated, thus keeping the minimum number operating at close to maximum efficiency. On increasing load the reverse cycle occurs and AHUs are sequentially reconnected to the system. Each floor zone can be isolated from the supply and exhaust risers by motorized dampers, allowing unoccupied areas to shut down whilst leaving other zones on the same system in normal operation and control.

Welfare and health concerns

CCTV is active in enhancing staff welfare and provides excellent working conditions. Beijing has the usual big city pollution problems, so CCTV required two-stage particulate filtration and also carbon filtration on all air plant to reduce pollution levels entering the building. CCTV also required a minimum 40% level of internal humidity - not to protect broadcasting equipment from static electricity, for which lower levels would suffice, but for occupant comfort. Their experience showed staff to have fewer respiratory problems if humidity levels are higher.

During design, the SARS outbreak caused serious disruption in China and to the performance of CCTV, who raised concerns that air-conditioning systems could distribute infection throughout the building. Arup's review of the World Health Organization and Hong Kong government reports on how the SARS infection spread confirmed that it was via an aerosol particle. Any recirculated air in the building would pass through the AHU filters, trapping aerosols, so air-conditioning would be unlikely to contribute to the spread of this infection; most would occur by close contact within the workplace. The team agreed with CCTV that plants serving broadcast functions would have the heating and humidification capacity to operate in an emergency without recirculation. In a future infection problem, the 100% outside air emergency override would allow these areas to continue operation with reduced dissemination risk, even if other parts of the building had to be shut down.

TVCC building

The TVCC tower contains multiple functions, including a 280-room hotel with restaurants, ballroom and spa, a 1500-seat theatre, digital cinemas, and large audio recording studios (Fig 5). The hotel rooms have a conventional four-pipe fan coil system, with other hotel functions served by all-air systems, including displacement. The theatre is a complex space with stage-level moveable seating, a multi-level adjustable stage and orchestra pit, and a large tiered balcony with 1000 seats, so the air-handling system needs to respond to different theatre configurations and audience patterns.

The tiered seating areas have a zoned floor plenum with underseat supply, whilst the lobby, flexible seating, and orchestra pits are served by variable volume displacement systems. As the audio recording studios have exceptionally low noise criteria, heavily attenuated dedicated plants and low velocity distribution ducts serve them via ultra low noise displacement vents at low level.

Mechanical services from the support building

Above ground, the support building will accommodate 200 site security staff plus garage and maintenance space for the TV outside broadcast vehicles. Roof-mounted cooling towers for the chillers and generator coolers require careful acoustic selection to meet the noise requirements at the site boundary. Below ground, the support building is the heart of the CCTV operation, containing the incoming power supplies and main 110/10kV transformers, standby generators, chiller plant including ice storage, and incoming district heating supplies and associated heat exchangers and pumping station.

CCTV was clear about the number and size of chillers it wanted to serve the site. The peak cooling load of 64MW was greater than originally envisaged, so a compromise was needed. To retain competitive bidding to sufficient suppliers, the chiller size was limited to 10MW; so six were needed (one standby), with two smaller 2MW chillers also included for efficient load operation. In addition, a further 10MW low temperature glycol chiller will serve a dedicated ice store capable of providing 25 000 ton hours (2110MWH) of storage. Arup's predictive analysis of monthly average cooling loads indicated that this size of ice store could be used efficiently throughout the year.
Multiple cooling towers (nominally two per large chiller) serve the water-cooled chiller plant, a decision that enables the minimum number of towers to run to meet the load, operating near peak efficiency. A hydraulically separated cooling tower provides free cooling for the chilled water system when outside temperatures are low enough.

By balancing the use of this tower with the ice storage and the smaller chillers, relatively low winter cooling loads are met with very low energy input. These strategies, coupled with variable flow chilled and condenser water pumping systems and the use of staged high efficiency VAV plants, allows CCTV to manage its energy input effectively with very significant reductions in energy input over more conventional approaches.

The chilled water is distributed to the basement of the two main buildings through service tunnels. Secondary chilled water pumps distribute throughout the lower levels and to intermediate level plantrooms, where plate heat exchangers and tertiary pumped circuits provide hydraulic separation to limit system pressures. There are ‘critical areas’ with a cooling load of 2MW and ‘operationally essential areas’ with an additional cooling load of about 8MW. Critical areas are served by the main chilled water system and by a second hydraulically separated and parallel system.

This system and its support systems are generator-supported and will use a small chiller or the ice store as the critical cooling source. Provided that a large chiller is available and one of the three incoming electrical supplies is operational, the essential area cooling loads can also be met. This hierarchy of load management allows CCTV to operate its critical broadcasting cooling with limited generator backup and, provided some incoming power is available, normal operation of most of the facility.

**Controls and commissioning**

*Introduction*

Each building has its own building automation system (BAS), operated and managed independently, but interconnected via the sitewide IT infrastructure, as both CCTV and TVCC must communicate with the support building. User access is via operator workstations in each building, and a building management system (BMS) provides common user access to the BAS and other building services subsystems throughout the development.

*Deliverables*

For the BAS Arup provided basic system requirements, instrumentation criteria and sequences for the major and more complicated systems, device schedules for all typical plant and panels, and single line control diagrams that reflected the systems described in the sequences. Control panels were located on floor plans.

The concept of detailing “typical” plant allowed the team to limit the amount of information it had to produce, but as the end of the extended preliminary design phase approached, the number of variants of each plant type increased, and it was a challenge to detail the information to avoid confusion and to pass on an accurate and useful document to ECADI. For the BMS Arup provided the requirements for the different types of network, and described the type of information that would usefully be exchanged between the BMS and the integrated subsystems.

The heating and cooling systems were based on a variable volume two-port valve concept - a type of system understood to be not common or well understood in China. To assist ECADI in the next stage, Arup therefore provided guidance notes on the selection of differential pressure control valves and two-port control valves as part of its design documents.

*Building automation system*

Some of the control functionality for the mechanical systems has already been described. On the VAV plant, terminal boxes on the floors were originally designed to have non-intelligent controllers, as there was a significant cost penalty in using intelligent controllers. More than 10 000 terminals would add significantly to the cost, size, and complexity of the control system.

However, following a controls workshop with the client engineering team, it was decided to adopt intelligent controllers for the VAV boxes. These would provide considerable future flexibility in reconfiguring boxes as the building use changed, and be able to monitor and respond to staff requests remotely, outweighing the additional cost. The BAS networks will need to be structured to ensure that system operating speeds are not compromised by this additional network traffic.

The chilled water system in the support building was a particular challenge. It is a typical, but very large, variable volume secondary and staged constant volume primary configuration, with primary pumps sequenced, all based on accurate measurement of the flow rate in the primary bypass. The complexity is in the primary circuit, which comprises medium and large water chillers with different sized primary pumps, used in combination with an ice store, glycol chiller, and free cooling plate heat exchanger.

The ice store utilizes the glycol chiller, and has sets of plate heat exchangers and pumps that operate depending on whether the ice is being made by the chiller, or whether the ice is being melted and providing cooling to the chilled water. Sequences were provided for the ice store to make best advantage of the electrical tariff structure. In simple terms, when electricity is cheap (overnight), the system makes ice and free cooling is utilized if external conditions are favourable. When electricity is expensive (mornings and evenings), ice is melted to assist primary cooling.
Building management system

The CCTV brief specified that there be a BMS to form a common user interface to the building services subsystems and a means of passing information between the different subsystems where there is an operational benefit. The subsystems would operate independently and not rely on the BMS for control.

The types of system deployed are similar to those at an international airport, and the concept here was based on systems integration work at London Heathrow Terminal 5. Interface standardization is a key objective for successful integration, and, using international standards, reduces system integration costs, eliminates the need for specific vendors, and allows more flexibility in selecting products.

The concept is for each subsystem to have a standard server, interrogated by the BMS. Graphical user interfaces (GUIs) connected to the BMS provide user access. Arup recommended that object linking and embedding for process control (OPC) - an industry standard method for systems to share information and work together - be a preferred solution for the servers. Alternatives such as BACNet (a data communication protocol for building automation and control networks) can also be considered; if a subsystem supplier cannot offer an OPC or BACNet interface, an alternative driver will have to be used or developed, but the intent is to standardize wherever possible.

The BMS software allows users to create and display graphics with data from multiple systems on a single screen, override plant operation, manage alarms, trend historical data, run decision support systems, and manage information between systems. Metered data is transferred to office billing systems, and alarms transferred to maintenance management systems. The access levels given to each BMS user define which tasks can be undertaken.

The systems interfaced using the server approach include the lighting control, building automation, fire alarm, electrical network management, and maintenance management. Others, such as security and CCTV, smart cards, emergency lighting, and car park management, are seen as standalone systems that will be monitored for fault via volt-free contacts by the BAS. Critical equipment rooms, which are provided with emergency lighting, and car park management, are seen as standalone systems that will be monitored via a wireless web server, and allow maintenance staff to view plant operating conditions and reset alarms when they are not near a workstation.

Commissioning and testing

Thorough commissioning and testing of building services are critical to the correct functioning of the systems. Arup established very early on that it was essential that the CCTV systems, though large and complex, be simply and swiftly commissioned once installed. Several features were incorporated into the design to achieve this.

The air-conditioning systems comprise VAV and water systems, and each was subjected to a theoretical commissioning review process, including considerations of maximum and minimum values and the essential components required to allow successful balancing of the systems at all levels of operation. The VAV systems were designed to be highly self-balancing, with low operating noise levels as a priority. Airflow measuring and regulating devices were included on the riser connections, with the VAV terminal units providing the local regulation.

The chilled and hot water heating systems were also designed for minimum on-site balancing, achieved by strategically locating differential pressure control valves (DPCVs), generally at each floor level, with orifice plates to allow calibration of them. Once calibrated, and at maximum demand, the DPCVs self-balance the system at approximate index circuits. Pressure test points are near all measuring instruments subjected to a theoretical commissioning review process, including considerations of maximum and minimum values and the essential components required to allow successful balancing of the systems at all levels of operation.

To verify pump flow rates, orifice plates are located in each distribution system. The pump speed control is accomplished by measuring system pressures at the pump. To verify system pressures, orifice plates are located in each distribution system. The pump speed control is accomplished by measuring system pressures at the pump. To verify system pressures, orifice plates are located in each distribution system. The pump speed control is accomplished by measuring system pressures at the pump.

6. Location of 10kV/400V substations.
The condenser water system incorporates several regulating stations to ensure that each water chiller and cooling tower receives its design volume of water. Particular attention was paid to their operating scenarios, with measuring and regulating stations being included to ensure each chiller receives a matched volume of condenser and chilled water.

**Electrical power supplies, service strategy, and 10kV infrastructure**

CCTV’s comprehensive project assignment and brief documents demonstrated its commitment to and ownership of the project to an extent very rare in early design stages. The scheduled room details for the three buildings, indicating the function, floor level, and area of each space, enabled Arup to convert the data into specific electrical loads and supply needs at an early stage. The brief also included statutory planning dimensions for electrical plantrooms, and categorized the technical loads into priorities, detailing the precise UPS (uninterruptible power supply) configuration for each category.

CCTV had also made initial estimates of the electrical capacity in the brief, and this was confirmed during design development. At the outset, CCTV had secured preliminary agreements for two 110kV city power network feeders routed independently to the site from different 220/110kV substations and a third 10kV network feeder from a local substation. As already noted, the development will be supported from two separate 110kV/10kV 63MVA oil-cooled transformers, each able to supply 100% of the total project load, but sharing it under normal operation as a safeguard. The third 10kV city power network feeder will support priority loads if a failure occurs on both 110kV feeders, when the electrical network management system (ENMS) will disconnect non-essential loads.

All these systems provide considerable reliability for the project’s electricity services, but for CCTV this was insufficient for some of their technical power loads and associated mechanical plant. These required further backup from standby generators, which will also support all life safety loads for the project.

The support building houses the Beijing Power Bureau incoming 110kV supply switchgear and their two large 110/10kV transformers, CCTV’s 10kV switchgear, 10kV standby generators, 10kV chillers, and other mechanical plant. The 10kV radial feeders of the duplicated site distribution system are run from the consumer’s switchboard and routed via separate cable routes in a service tunnel to the building basements. High-voltage risers feed distribution substations with duplicate cast resin transformers, each sharing around 50% of the load. The CCTV building alone has 25 of these, each serving specific technical or departmental loads (Fig 6). Another five serve TVCC and its hotel, and there are five more in the support building.

The elevator consultant specified over 90 elevators and 21 escalators for the whole project (Fig 7), which contribute 8.36MVA to the total connected load. Two substations, one in the top of each Tower, are dedicated to supplying some of this. To limit the size and number of escape stairs in the Towers, the lifts are used in parallel with the stairs. This means that the power supply to the lifts is generator-backed, and cooling to the lift motor rooms is on the ‘essential’ circuit.
The overall estimate of maximum electrical demand for the site is in the order of 60MVA, with maximum estimates for the individual buildings being CCTV: 41.46MVA; TVCC/hotel: 8.68MVA; support building: 16.58MVA; plus 2.00MVA allowed for future development of a media park (Fig 8).

The ENMS will control and manage the normal and emergency functions of the duplicate 10kV and 380V infrastructure, with links to the BAS and the generator load management system (GLMS). The ENMS will identify and plan for periods of peak demand, and enable maintenance schedules to be based on actual operating history, identifying and providing diagnostic information on faults to help CCTV take preventative action and avoid forced electrical interruptions.

The switchgear cubicle controller on each 10kV feeder circuit will manage the switching functions of circuit breakers and bus section switches in the various predetermined load scenarios associated with loss of power, generator operation, and load shedding. The system will also enable energy consumption to be monitored at various points, such as incoming supplies, main feeders, and major loads. Each cubicle controller will also be capable of horizontal communications, allowing for pier-to-pier communication for load shedding, recovery of the load, and internal harmonic analysis.

The ENMS is based on a powerful dual redundant SCADA (supervisory control and data acquisition) concept, utilizing a dedicated communication infrastructure based on industrial Ethernet technology to form the backbone to which all ENMS communication equipment will connect.

The network infrastructure will be a dedicated fault-tolerant Ethernet fibre optic sitewide ring; avoiding any single point of failure and loss of availability, it will have industrial Ethernet switch hubs connected at strategic locations. Links to the BAS via a remote terminal unit will report the status of the three power supplies, the generators, and the busbar configuration of the consumer’s 10kV switchgear. It will also ensure the planned reconnection sequence of all mechanical plant to suit the third 10kV supply and generator load scenarios.

The brief considered that the standby generators should be arranged for 380V operation, but lack of suitable plant spaces at the appropriate substation locations, and the circuit lengths necessary from centralized plant, resulted in a high voltage solution. Six 10kV 2200kVA generator sets running in parallel under the control of the GLMS will provide optimum use of the available capacity and give ultimate priority to life safety loads, supplying power via the normal duplicated 10kV and 380V infrastructure. The CCTV building’s life safety load was considered when determining the likely total capacity, as this is the largest total load of the three buildings and fire in all three simultaneously is extremely unlikely.

The hotel has 100% backup, as required by its operator, but normally across the remainder of the site only the technical and associated loads will be supplied. In a developing emergency, where all incoming city power to the site has been lost and a fire or evacuation scenario occurs causing life safety plant to start, the GLMS/ENMS will start the remaining generators and manage the load in response to the increasing power demand.

On this basis the estimated generator capacity required for the site is 9200kVA for technical, etc, loads/CCTV life safety loads, and 3600kVA for the hotel load (fully-diversified), totalling 12 800kVA.
Piped services

Both CCTV and local codes required greywater in addition to cold water and drinking water, giving three cold water systems to integrate into an already complex building.

The main water storage in the basement is transferred and distributed to draw-off points throughout the CCTV building. As for other services, its size and height made special demands, in this case dictating four pressure zones; this was complicated further by the presence of the two Towers. Intermediate break tanks, with variable volume pump sets and sensitive pressure-regulated control, will avoid excessive operating pressure and comply with local plumbing code requirements.

The drinking water will be derived from the incoming domestic main, and then treated with localized particle and UV filtration at each zone before passing into the storage tank. Distribution will be as a pumped circulation main to constantly turn over the supply and avoid stagnation.

To maintain the water systems’ integrity, the wastewater will also be separated to collect grey water from wash hand basins, showers, air-conditioning condensate drainage, and waste cooling water. The local authority is proposing to treat and return grey water from a centralized city plant.

Fire suppression

The entire development includes many categories of fire risk, each requiring a different type of fire suppression system. CCTV preference, local fire codes, results from fire engineering analysis, and architectural intent all influenced the choice of system. These include:

- street hydrants around the perimeter of all three buildings to protect external areas and façades
- internal fire hydrants and hose reels on the floors, positioned so that the jet of two fire hydrants or hose reels can reach any point
- water cannon extinguishing systems in CCTV’s main entrance lobby and the TVCC atrium, as their height exceeds the effective operating height of the fast response type sprinkler system
- foam cannon extinguishing system to protect the helipad on the CCTV roof
- deluge systems for the CCTV studios and TVCC theatre stage, with open type deluge nozzles installed under the latter’s grid
- water sprays for the diesel generator rooms
- sprinklers in offices, hotel rooms, all general areas, corridors, and lobbies (fire hazard classification Medium Hazard II)
- Inergen (mixture of nitrogen, argon and carbon dioxide) gas suppression systems for ‘sensitive’ rooms where water spray risk was a concern and cleanup of residue can be a problem. These are fed from a centralized supply and are divided into nine zones in CCTV and seven zones in TVCC.

Over 200 ‘sensitive’ rooms containing recording and broadcasting equipment and recorded programme material require special fire suppression, which had to take into account local fire codes and CCTV’s design brief. These requirements called for either a gaseous flooding suppression system or a water-based pre-action type. CCTV considered the water-based system unsuitable due to the potential for water damage.

Large gaseous suppression systems require the room construction to be reasonably airtight, and robust enough to survive the rapid discharge of extinguishing gas. Also, pressure relief ducts from each room to the outside are required. These provisions attracted additional cost and construction time, as well as valuable space for relief ducts, so the team investigated other possible solutions.

Arup recommended a water mist extinguishing system, in which mist under high pressure cools the room, reduces oxygen, and scrubs smoke. This system swiftly extinguishes and cools a fire with minimal water, thus reducing the risk of water damage and removing the risk of re-ignition inherent in gas suppression. It has been used in the marine industry for many years and is developing for sensitive building applications. However, CCTV decided to stay with the familiar technology of gas suppression. Of the gases available in China, Inergen was selected as the most environmentally acceptable, with a low safety risk for personnel.

Conclusion

The MEP schematic design was completed in May 2003 and the extended preliminary design (EPD) in February 2004. Handover of the very complex EPD took several months of detailed correspondence and meetings with CCTV and ECADI. The post-handover Arup role is to answer technical queries and to comment on the ECADI construction stage documents.

Credits

Client: China Central Television
Architect: OMA Stereobouw BV
MEP, geotechnical, structural, fire, and security consultant: Arup - Olly Base, Chris Brown, Jun Chen, James Cheung, Kenneth Chong, Chi-Wing Chow, Judy Coleman, John Coppin, Chai Kok Eow, David George, Dane Green, Alistair Guthrie, Maggie Lam, Bob Lau, Iain Lyall, Adam Martin, David Pritchard, John Pullen, Clodagh Ryan, Eddie Scuffell, David Seager, Lewis Shiu, Kenneth Sin, Jodh Singh, Glen Swinney, G B Wang, William Wong, Sabrina Wong, Alba Xu, Ming Yang (see previous article for Arup analysis, structural, and geotechnical credits)
Illustrations: 1 Arup/OMA/Nigel Whale; 2–4, 6–8 Nigel Whale; 5 Arup/OMA; 9 Arup

Reference


The next article in this series, discussing the security systems design of the CCTV development, will appear in The Arup Journal, 2/2006.