



Report on Half-Day Seminar on “Engineering Aspects of Lessons Learned and Beyond”

By: Ir. Chua Chai Guan

Is it necessary to get this high? Are skyscrapers really an outcome of high population growth and land scarcity? Once upon a time, Malaysian was so indulged with the Petronas Twin Towers which were the tallest buildings (452m) in the world between 1998 and 2004. It was built at a cost of about US\$1.6 billion (US\$4050/m²). Now we have a chance to glance into the “Building of the Century” – Burj Khalifa which holds the title of the tallest structure (828m) in the world now. At US\$4850/m² the unit area construction cost is about 20% (on face value without taking into account of inflation) higher than that of the Petronas Twin Towers.

The Geotechnical Engineering Technical Division and Civil and Structural Technical Division invited Ir. Angus McFarlane, Dr Andrew Davids and Dr. L. Tony Chen from Hyder Consulting and Dr. Volker Buttgeriet from BMT Fluid Mechanics to share their precious experiences in designing and supervising the construction of the tallest building in the world, through a half-day seminar entitled “**Engineering Aspects of Burj Khalifa – Lessons Learned and Beyond**”. Held at Tan Sri Chin Fung Kee Auditorium Hall of Wisma IEM on 30 May 2011 the seminar attracted about 100 participants.

Ir. Angus McFarlane started his talk entitled “**Burj Khalifa - Design and Construction of the World's Tallest Building**” by explaining Hyder’s role in Burj Khalifa. They were involved in geotechnical and foundation design and construction supervision, as well as certification and adoption of the Architect’s (SOM, Skidmore, Owings & Merrill) design in structural design, mechanical, electrical and plumbing (MEP) design, façade design, architectural base-build, peer review and master planning and infrastructure design of Downtown Dubai. Legally, Hyder is the Design Consultant for the tower.

“The core system of this tower is made of a hexagonal core reinforced by three buttresses that form the ‘Y’ shape which enables the unprecedented high building to support itself laterally and keeps it from twisting,” said Ir. Angus. As the tower rises, setbacks occur at each element in an upward spiralling pattern, decreasing the cross section of the tower as it reaches toward the sky (see Figure 1). At the top, the central core emerges and is sculpted to form a finishing spire.

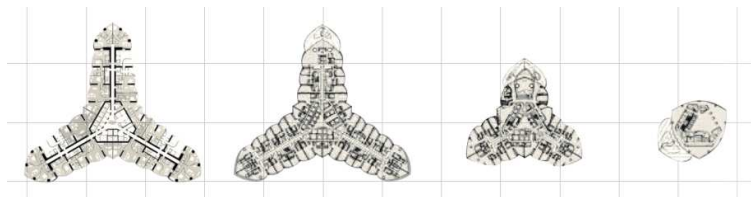


Figure 1: Y-shape layout plan at different terraces

He stressed that many re-engineering has been done including the concrete mix designs used on the tower, through which concrete was pumped to a record height of over 600m in a single stage. Besides that, extensive vibrational testing of the tower and long term structural health monitoring program were carried out to confirm the design assumptions.

He shared that the leading edge construction technologies by joint venture Samsung-Besix-Arabtec were self-climbing formwork, steel connection details and strand jacking of the final pinnacle section of the spire to curtain walling detailing and builders' work provisions to ensure easier MEP installations whilst maintaining the original intent of the architect's design.

One interesting construction activity to note is that the concrete was cast at night when the air was cooler and the humidity higher. This is to ensure that the concrete mixture cures evenly throughout and prevent it from setting too quickly and cracking.

The whole construction took about 6 years to complete, see Figure 2.



Figure 2: The tallest building - Burj Khalifa (828m high)

The second speaker, Dr. Andrew Davids talked about ***“Beyond Burj Khalifa - Designing the Next Generation of Sustainable Ultra-Tall Projects”***. He elaborated the feasibility of the tallest tower from the perspectives of economy, living comfort and sustainability.

He revealed that the Burj Khalifa by itself was not a feasible project as the investment return required many years. The key success was to blend it into a township development. With the presence of the tallest tower, the value of adjacent properties increased phenomenally. As a result, it helped to recover the cost of that tower. The Burj Khalifa serves more than a monument and has the capability to earn money, as well as to be the frontrunner in developing the city.

Notwithstanding the above, the construction of the Burj Khalifa also faced the pressure of a 20% p.a. inflation rate. To overcome this, Hyder enhanced the buildability of SOM's design by standardizing the dimensions of the walls and columns, changing the details of the steel work; tested materials – particularly the glass and stainless steel of the facade. “The more you can standardize it, the more efficient the construction will be,” explained Dr. Andy.

Like any other buildings, the Burj Khalifa is designed essentially to offer shelter and to provide a pleasant environment to live and work in. Hence, all humanised factors like motion sickness due to swaying of building, building reflectivity, aeronautical impacts, elevator system, water system, air-conditioning, air quality and visual impacts and Dubai's extreme summer temperatures have to be taken into account. One example is that its façade consists of glazing with low UV and high shading to help reduce internal heat gains. As a result, it reduces the size of the air-conditioning plant required.

At the end of his talk, Dr. Andy postulated that the next generation of tall buildings could be in the range of 1 km to 2 km as the relevant accumulated expertise would have been ready to embrace the next challenge.

Dr. Volker Buttgereit presented the talk entitled "**Wind Engineering - Supercomputing and Wind Tunnel Contributions to the Quest for Sustainable Ultra-Tall Projects**". One of the challenges dealing with a super-tall building is to understand the interaction between winds and the building.

Dr. Volker explained that every super tall building had a great deal of area that the wind could push against. The wind could form a wake similar to what is observed behind a boat with vortices shedding off, alternating on either side and pushing the building from side to side. This pattern of wind is called **vortex shedding**. Should those vortices resonate with the frequency of the building, the induced oscillation would cause even the most rigid skyscrapers to sway slowly back and forth. In the case of the Burj Khalifa, the building swaying can be up to 1.5m at its top which is in the order of 1/500 of its height. This motion is acceptable should the acceleration is less 5 to 25 milli-g which is the threshold value can be sensed by human beings.

Prior to construction, a complex and rigid scale model was constructed for wind testing. The replica went through several rounds of testing in a specialized wind tunnel. The wind tunnels were designed to simulate changes in the wind speed with height and could replicate the variable wind environments in which the tower would ultimately be constructed. Inside the tunnel, the model was rotated at all different angles and wind effects were sometimes visualized using smoke. All of this data was then fed into a super computer model in order to perform additional analysis. This wind tunnel testing led to a dramatic design change i.e. the entire building was rotated 120° to reduce wind loading.

Another innovative design to note is that the organized flow of wind around the building was intentionally disrupted by introducing changes to the shape of the building with height. It is almost like having several different buildings with height and each one of them has different vortices shedding at different winds speeds. As these things could not happen at the same time so there would be very little vortex shedding.

The last speaker of the seminar was Dr. Tony Chen who delivered his talk entitled "**Geotechnics and Foundation Designs Associated with Super High-rise Buildings**". He presented the geotechnical properties of the sub-strata which were obtained from a comprehensive ground investigation. A detailed finite element analysis was undertaken, which resulted in the adoption of a piled raft foundation system comprising a 3.8m thick raft with 192 numbers of 1.5m diameter bored piles.

Dr. Tony Chen mentioned that the piles were socketed into weak rock where the capacity is mainly derived from the skin friction developed between the pile concrete and rock. Noticeably the design of the foundation was found to be governed primarily by the tolerable settlement of the foundation rather than the overall allowable bearing capacity of the foundation.

He also shared that the potential of reduction in axial load capacity and stiffness of the foundation strata under cyclic loading was investigated via pile load tests, laboratory tests and theoretical analyses and was found relatively small.

Dr Tony Chen highlighted that the test piles were loaded to 60 MN. It is interesting to note that the working piles have performed even better than the preliminary trial piles, and have demonstrated almost linear load-settlement behaviour up to the maximum test load of 1.5times working load.

The seminar was followed by an active exchange of opinions between the speakers and audience. It then concluded with a rapturous applause from the floor.