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Design of tall buildings

***Jenny Burridge** of **The Concrete Centre** looks at the latest trends for tall buildings and considers some of the design, construction and material property benefits that the use of concrete brings.*

There was speculation, after the Twin Towers disaster in 2001, that tall buildings would subsequently be avoided and the 21st Century would be the century of the low- to medium-height development. This has proved to be unfounded. Of the world's 20 tallest buildings, all but two were built in the past 20 years. The tallest building at present, the Burg Khalifa in Dubai is, at 828m, 80% higher than the Petronas Twin Towers, which was the tallest building in 2000, at 452m. The Jeddah Tower, formally known as the Kingdom Tower, is partially constructed and has been designed to be at least 1000m.

Tall buildings in the UK

The London Tall Buildings Survey, produced annually by New London Architecture (NLA), shows 60 new tall buildings were completed last year, 89 were started on-site and 308 were granted planning permission. Many of these are mixed developments, but most of the floor area constructed is for residential use. Concrete is the structural material of choice for the majority of tall residential buildings due to its inherent acoustic, vibration and fire-resistance properties.

For the NLA London Tall Buildings Survey, 'tall' is considered to be 20 storeys or more. This would not be the case for other places in the world where 30 storeys and above would be considered tall. Structural engineers tend to define a tall building as being where either the lateral loads dominate the design, or where the ratio of the height to the smaller horizontal dimension is greater than five.

Another defining characteristic of a tall building is that the vertical transportation of people and services becomes a key feature of the design. The core provides stability for the building but also provides lifts, stairs and service risers. The lift strategy needs to be well understood in the early stages of the design as this will determine the amount of floor area that needs to be used for the core. The number, size and location of the lifts are determined by the use of the building and the occupancy. Office buildings need lifts that can accommodate high levels of traffic at the start, middle and end of the day as workers come in, go out to lunch and then go home. Residential traffic is more constant throughout the day. Once the lift strategy has been determined then the core design can begin.

Core design

The core of a tall building is arguably the most fundamental and important element under consideration during the design process. For most tall structures, the core forms the main backbone of the building and plays a significant role in carrying a large proportion of vertical loading and, frequently, the majority of lateral loading.

An inefficiently planned core will lead to slower construction and wasted floor area, which increases cost.

Core wall thicknesses may vary between 350 and 600mm or more for buildings up to 200m tall. The concrete strength will have a direct influence on the thickness of the core walls and for taller buildings it is common to use high-strength concrete for the columns and core walls. It is important for structural engineers to make an early estimate of wall thickness and thus allow architectural planning of appropriate structural zones. To resist applied lateral loads and resultant overturning, the design should maximise vertical loading carried by the core, as this helps resist tensile forces produced by overturning moments from the lateral loads. In planning its layout, the

Left: Jeddah Tower, Saudi Arabia.

structural efficiency of the core is improved if the column arrangement outside the core is such that floor spans onto the core walls are maximised. This also minimises difficulties with differential shortening. Typically, the core may support 60% of the vertical loading.

In most tall buildings in the UK, the core is the primary structural system taking the lateral loads. Other options are available when the building is taller or is particularly slender. The 432 Park Avenue building in New York has an aspect ratio (height to smallest horizontal dimension) of 15 and a height of 426m. The structural system is 'tube in tube', where the core and the external walls act together to resist the lateral loads.

Where possible, the core should be placed at the centre of the building so that torsion or twisting loads are avoided. Where this is not possible, the core must be designed for the additional loads.

Floors and columns

For any tall concrete building, the effects of differential axial shortening, due to the different levels of axial stress in the columns of the building compared with the walls/core, must be considered in structural design.

Core walls are generally quite large, with their size influenced by both axial stress requirements and stiffness requirements to resist lateral loads. Columns, by contrast, are usually kept as small as possible and are generally more heavily stressed. Columns and core walls undergo elastic and creep shortening at differing rates. This affects the floor slab and can alter the distribution of moments and shear forces around the floor plate. The differential relative settlement of supports can also affect the levelness of floors, if not carefully considered and compensated for in design and construction.

Flooring systems are normally post-tensioned or reinforced concrete flat slabs, to maximise the number of storeys for a given building height. At 240 Blackfriars Road in London, the use of thinner post-tensioned slabs instead of traditional reinforced concrete allowed two more storeys to be created without increasing the building height. The use of hybrid or precast construction is becoming more common as the speed of construction enables shorter build programmes.

Construction method

It is important in the design phase to consider the buildability of the structure and the building as a whole. Most cores are built using either jumpform or slipform construction, but there are some off-site options, such as twin wall and modular core units. The shape and complexity of the core will help to determine the method of construction, but the use of the building and contractor preference will also have an effect. In slipform construction, the core is built well ahead of the slabs and tends to be used for commercial buildings. For example, The Shard in London has a slipformed core as the lower storeys are offices. In jumpformed construction, the floors are brought up only slightly behind the core. If the concrete is to be left exposed in the finished building, then slipform construction should not be used as the surface finish is not as good quality as that produced by jumpform or precast solutions.

Most clients want a tall building to be built as quickly as possible. The form of the core and the floor slabs are therefore normally determined by what is the simplest and quickest solution. Standardisation of element dimensions and early-age strength gain of the concrete can have a big influence on the floor-to-floor cycle time. Additionally, the use of post-tensioned slabs allows the formwork to be struck earlier and moved on more quickly.

Fire and sustainability

One aspect of design that has taken on a more prominent role in the past three years is fire resistance. The second phase of the inquiry into the Grenfell Tower tragedy in June 2017 is currently underway. The 24-storey tower was a reinforced concrete frame, but the retrofitted external cladding spread the fire to the whole of the building in a very short time, resulting in the loss of 72 lives and many others are still suffering from the trauma.

The concrete frame itself has survived the fire, having been subjected to a fire duration of many hours, rather than the two hours required by Building Regulations.

Concrete has inherent fire-resistance characteristics, with the concrete cover providing insulation to the reinforcement. Fire-resistance periods of two hours can be easily achieved, which is the typical requirement for tall buildings. As a non-combustible structural material, concrete does not burn and can be used to meet and exceed stringent requirements for the fire safety of people and property.

Another aspect of design that is becoming ever more urgent is sustainability, in particular the embodied carbon in buildings. Tall buildings are inherently higher in embodied carbon per square metre of usable space than low-rise buildings. However, this can be offset to a certain extent by the reduction in travel distances for high-density urban spaces. The design of the concrete can reduce the embodied carbon of the structure, but needs to be considered together with the other aspects of the design. The need to pump the concrete up to a high level influences concrete mix design and tends to lead to stronger concretes being used, even if not specified by the designer. When this occurs, designers can take advantage of the stronger concretes in the design of the floor slabs.

The foundations tend to be massive so there is a good opportunity to use cement with high levels of additions, such as a CEM IIIB. This significantly reduces the embodied carbon of the concrete and has the additional benefits of being more durable in aggressive ground and having a much lower heat of hydration, reducing early-age cracking in large pours. Early-age strength is not an issue as the foundations are not fully loaded for many months.

Optimum solution reached

When designing tall buildings, the design team needs to work closely together and with the contractor to address the various factors that influence the layout of the building and, in particular, the core. Only by working together can the optimum solution be reached. Tall buildings are a vital part of our city landscape and should be designed to last many years so that the full benefit can be realised for us and future generations. ■

The Shard under construction, London.

(Photo: MPA/Daybreak Communications.)