Height of innovation

The last of the steel to top out the 87-storey Shard building was installed on 30 March. This involved some of the most forward-thinking design, fabrication and erection methods

PROJECT REPORT
RUBY KITCHING

Project The Shard, London
Client Sellar Property Group
Architect Renzo Piano
Main contractor Mace
Structural engineer WSP
Steelwork contractors Severfield-Reeve Structures, Atlas Ward Structures, Steelcraft Erection Services

"It's been quite an experience – very challenging, but very innovative," says Doug Willis, contract manager for steelwork contractor Severfield-Reeve, which is working on the Shard. Speaking to *Construction News* just days before the last pieces of steel were to be installed to top-out the tallest building in the UK, he is proud of what has been achieved.

These last pieces of steelwork make up the 60 m-tall steel-framed spire which will accommodate a viewing gallery and plant, and sits on top of the 310 m-tall mixed-use structure. The 87-storey building will be the tallest in western Europe, housing 25 levels of offices, three restaurant levels, 19 levels of hotel accommodation, 13 levels of apartments and a viewing gallery.

Construction of the spire, which rises from level 72 with its base 250 m above ground level, is a major feat of engineering. Main contractor Mace, steelwork contractor Severfield-Reeve Structures, Select Cranes, structural engineer WSP and architect Renzo Piano Building Workshop have worked together to ensure the highest levels of safety in the erection of the spire.

The challenges of working so high up include high winds, frostbite and low clouds, and are particularly troublesome during the winter months. Wind speeds reportedly reached 185 kph during a period of downtime last month, and so the programme and the method of construction had to take these extremities into account.

310 m
Height at which the Shard tops out

13k
Tonnes of steelwork used

"It's a very tall structure anyway and building the spire on top has been a very interesting challenge," says Flan McNamara, project director for developer Sellar Property Group.

"Severfield-Reeve's solution was to prebuild most of it [the spire] offsite to completely de-risk the project.

"We've actually been slightly ahead of programme, despite the effects of [downtime caused by] high winds."

Crane (TC7), with its base fixed at level 55 and propped in two locations 20 m further up the building, lifted each cassette up to its final level

IMAGE COURTESY OF IN-PRESS

Weather watch

When wind monitoring equipment on the top of the building measures speeds greater than 55 kph, steelwork erection comes to a halt.

Building the spire offsite in modules was an obvious choice for Severfield-Reeve, to ensure it could be built in as few pieces as possible – leading to fewer crane lifts and less time spent erecting the structure in the air.

But the team took this further, carrying out an offsite trial assembly at its Dalton Airfield site in North Yorkshire. The contractor even used the same erectors for the trial as for London Bridge.

The spire was set out and fixed onto support points identical to those they would find at level 72 on the Shard.

"No one has ever built a 23-storey structure 250 m up in the air, so it was apparent that a trial assembly was important, especially in terms of understanding the spire's geometry and fit," says Mace senior project manager Adrian Thomson.

"No one has ever built a 23-storey structure 250 m up in the air, so a trial assembly was important"
ADRIAN THOMSON, MACE

The solution involved splitting up the structure into two-storey sections and dividing the floor plate into manageable and logical pieces, or cassettes. This resulted in far fewer onsite bolted connections, and more offsite welding. So when the weather was favourable for erection, the cassettes and erectors could be on standby to make the most of the time available.

"We would have lifted the spire in one 500-tonne piece if it had been possible, but we were limited on weight to less than 7 tonnes per lift," says Mr Thomson.

Dividing up the floor plate and storey heights was a painstaking ▶

MAIN STRUCTURE DESIGN

For structural stability, a slipformed concrete core rises up through the building, reducing in footprint from 22 x 20 m at ground level to 7.5 x 11 m at level 72. Above this level, the core is continued up through the spire using steel elements.

Since the building does not rely on a tuned mass damper to act against perceptible wind-induced sway, extra stiffness is provided in the building by way of a steel 'hat truss' between levels 66 and 68.

The core is therefore connected to the perimeter columns at these levels via a system of steel bracing, effectively engaging the perimeter columns to provide additional lateral stiffness.

"By playing with the mass of the building and analysing its dynamics and with extensive wind tunnel testing, we were able to design the building without a tuned mass damper – which would have weighed more than 600 tonnes," says WSP project director Kamran Moazami.

"It would also have taken up two floors and would have cost a few million pounds to include."

Material demands

The hybrid building concept means substantial transfer structures are required when the structural material changes between floors.

Between levels 37 and 41, perimeter load-sharing vierendeel trusses allow transfer of the load from upper, closely spaced perimeter columns at hotel and residential concrete floors (typically 3 m centres) to the lower longer span perimeter columns at office floors (typically at 6 m centres).

Web and flange thicknesses of the Fabsec steel beams on the office floors vary but all are a constant 500 mm deep, with 300 mm diameter openings for services. This has made threading services through the beams very straightforward, since the holes are all at the same level. Automated fabrication processes have aided achieving this level of detail, so the Fabsec beams have thicknesses which suit their specific load conditions.

Paths to safety

Recommendations in the wake of 11 September attacks in 2001 for tall building design have been included.

"We have systematically checked the building in accordance with recommendations post 9/11 and used extensive non-linear dynamic computer analysis to demonstrate that if some elements were removed the building would deform and develop alternative load paths to ensure that it would stay standing up," says Mr Moazami.

Since the building tapers as it rises, all floors have a smaller area than the one below. But aligning columns that start and stop at different levels and setting out and fixing brackets for the glazed wing walls that oversail the corners of the pyramidal structure was challenging, admits Mace senior project manager Adrian Thomson.

"Even the pitch of each Shard [face] varies: some are 5.91 degrees, while some are 5.8 degrees, so there is a constant need for strict and tight dimensional control. We regularly used 3D models to check the structure".

Axial shortening of columns and settlement also had to be considered on the project, so significant monitoring had to be carried out and adjustments made throughout the build.

THE SPIRE: SAFETY IN DESIGN, FABRICATION AND ERECTION

The 60 m-tall, 530-tonne spire is made up of 460 pieces of steel and was built off level 72 of the Shard. To build it safely and efficiently required the design-and-build team to work together very closely to achieve the best solution.

"Our first thought was to get WSP's design as early as possible so we could be involved with the design of the spire, rather than get the [completed] scheme and then try to make it work for the programme," says Doug Willis, contracts manager for Severfield-Reeve (part of Severfield-Rowen Group).

"It had to be designed in a way to suit manufacture and safe erection, which came down to looking at the size and number of pieces and how they would bolt together."

The solution was to build the spire in modules offsite – not just the side elevations, but also the floors.

Since the spire will not be inhabited, there is only a floor every three levels up and circulation and access relies on steel stairs within a central steel-framed core and catwalk-style gantries and ladders.

The external structure comprises a perimeter truss which supports the cladding.


Trial assembly at Dalton Airfield in North Yorkshire

Each floor is very different. At level 72 it is composite deck, at level 75 a solid steel plate with waterproofing detailing (this is actually the Shard's roof, since above this level the structure is open to the elements), and above level 75 the floors are made up of open aluminium flooring or a galvanised steel grill.

"By building the spire in two-storey modules, we wanted to reduce the number of onsite connections and lifts so we could concentrate on health and safety," says Mr Willis.

Each module was able to include elements such as the main structure, floor, catwalk gantries and cladding rails. However, where pieces became too large, they were erected as individual entities – such as for some cladding rails. To simplify some of the column-steel core connection details, stubs were pre-welded onto each component to make them easier to locate.

The sequence of construction consisted of erecting the central steel core first, then installing a temporary steel platform to support mobile elevated work platforms, which would be craned into position.

The MEWPs allowed the steel erectors to build the external truss which would then cradle the modules, known as cassettes. Further connections were made possible by attaching erectors to a gallows-frame type post which sat on top of the steel core.

Assured fit

"A trial assembly offsite made sure every bolt fitted in every hole so that on site, the guys in the MEWPs could bolt the underside of the module and the guys attached to the gallows could complete connections above," says Mr Willis.

The coordination involved was meticulous. Where brackets had to be incorporated into modules for lifting purposes, part of the floor plate would have to be left out, and would need to be installed when the floor above was being connected.

The MEWP platform and gallows frame had to be rebuilt as the spire gained height, not forgetting that the stairs could only then be installed in the core.

At level 87 there is also a requirement to have a building maintenance unit, which sits on stubs on the steel core.

The steelwork cantilevers about 20 m off level 87, which created a further challenge since it would be more exposed to the elements.

So Severfield tested different types of netting to protect it during erection, settling on a net to provide sufficient fall-arrest protection while ensuring it was not too dense to have a sail effect.

Mr Willis says: "The spire just doesn't compare with anything you'd ever build anywhere – but the trial assembly resolved all the connection issues."

"We just had to offer the pieces in, and they fitted"

DOUG WILLIS, SEVERFIELD-REEVE

▶ task. In some cases WSP redesigned I sections as two separate channels when they straddled two lifts. Cover plates and packing plates were also preassembled offsite to reduce the amount of work and adjustment required onsite.

Since the public will be able to view the structure close-up in the viewing gallery at level 72, Severfield-Reeve also had to ensure the steelwork finish was to a high standard and that some connections were concealed for architectural reasons. The number of cassettes per floor diminishes from six on the lower floor of the spire to one at the top.

"Initial trial assembly ensured that all connections were within the required tolerance," says Mr Thomson.

"We then worked with Severfield-Reeve to ensure higher than normal tolerances to have a better fit of connection."

The fit became so exact that guide columns were no longer required to slot the cassettes in place. "We just had to 'offer' the pieces in, and they fitted with just a bit of 'teasing' – that attention to detail paid dividends."

Severfield's erectors were hand-picked for the spire and they spent time on the trial assembly honing their skills, lifting and slinging the cassettes into position, giving them extra confidence.

Connection made

The onsite procedure for erecting the spire included taking the steelwork off lorries and then assembling it on the ground floor according to each cassette's configuration.

A crane (TC7) with its base fixed at level 55 and propped in two locations 20 m further up the building lifted each cassette from the ground up to its final level.

Here operators positioned on mobile elevated work platforms, or fixed access platforms and connected to lanyards, steered each cassette into position. Once aligned, seven or eight connections had to be made to fix the cassette to the existing structure.

The first spire cassettes are connected to the main building using post-tensioned Macalloy holding down bolts embedded 3 m within sleeves in the concrete at level 72. There are four such Macalloy bars at each corner of the spire.

WSP project director Kamran Moazami says: "The main bracing elements of the spire are within a steel-framed core.

"Steel was the obvious choice because it is lightweight and strong and elements can be prefabricated offsite. Steel can also stand up to the harsh environment up there."

STRUCTURAL VARIATION

"This is the most exciting and best-looking building in the world," says WSP project director Kamran Moazami as he describes the mixed-use Shard, which is nearing structural completion.

As the lead structural engineer on the project, Mr Moazami is of course completely biased. But as someone who has been involved with tall building design for more than two decades, his perspective has some validity, and his enthusiasm is clear.

"It's a building where we, as a team, have used every tool in the box to make it viable and get it built," he says.

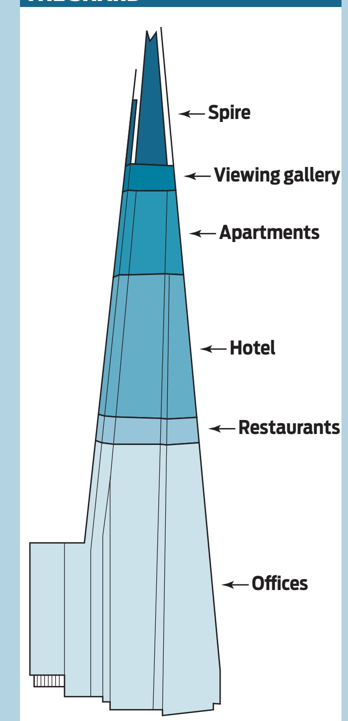
The building comprises a hybrid construction, using the most appropriate structural form and material for each occupancy type.

Reinforced concrete is used for the three-storey basement, ground floor reception area and first floor, but the structure quickly switches to a composite steel framed structure for the offices from level three to level 40. Level two is a post-tensioned concrete structure.

Throughout the hotel and apartment levels between 40 and 72, post-tensioned concrete is used – as much for acoustic purposes as for creating mass at appropriate levels of the building to help counter the perception of movement induced by wind loads.

Above this level is the spire structure, which has three triple height floors and is of steel-framed construction, taking the building to its peak at level 87.

THE SHARD



PIONEERING PYRAMID

Described as London's first vertical city, the Shard sits on London Bridge Station, just south of the River Thames in the London Borough of Southwark, an area under redevelopment.

The site, previously occupied by Southwark Towers, was acquired in 1998, but planning permission for the building was not granted until 2003. Demolition began in 2008 and the building is due to open in September 2012.

The Shard is made up of 16 'shards of glass' on the facade, each sloping about 6 degrees from vertical. While the building looks like a pyramid, there are levels where the façade straightens up and even slopes outwards to facilitate greater floor areas.


The Shard will be Europe's tallest building

Thermal mass and steel

Cutting CO_2 emissions using the ability of a building's fabric to absorb excess heat – its thermal mass – is a simple and effective measure, but more is not necessarily better for optimal efficiency

DESIGN
RUBY KITCHING

Optimum thermal mass is provided by the first 100 mm depth of an exposed concrete ceiling – which means steel-framed buildings can achieve the same level of natural cooling as concrete ones.

Thermal mass is the ability of a building's fabric to absorb excess heat. The part of the fabric that has the most thermal mass is its concrete floor slab.

But to work most efficiently this needs ceilings to be left exposed – which means no false ceilings.

The science of mobilising thermal mass assumes that during the day, solar gain, electrical equipment and human activity generate heat, which warms the air in a building.

Ordinarily, air-conditioning equipment would be needed to artificially cool a building down to a more comfortable level.

If concrete ceilings are left exposed, as the warmed air rises, it is absorbed into the fabric of a building. This keeps the temperature in the building down, so less mechanical cooling is required – saving energy and money.

At night, cool air is allowed into the building and this flows across soffits to return the concrete to its original temperature, ready for the next morning where it begins absorbing heat again.

Over the 24-hour cycle, a maximum of just 100 mm of concrete can absorb and store and release heat. Buildings such as offices and schools that see a lot of activity in the day but none at night can benefit from being designed to maximise their thermal mass potential.

"If you can make a building passive from a design point of view, you save energy and the building will remain low-carbon for the rest of its life," says Mott MacDonald technical director Edward Murphy.

"Thermal mass is most effective when concrete ceilings are exposed, since this is where warm air collects, but the contribution is much less from concrete or masonry walls."

Overheating

There is a common misconception that a heavier structure will perform better thermally, but having too much mass can be counterproductive. During periods of warm weather, when it is not possible to cool the exposed concrete at night, the heavy elements may absorb so much heat that this becomes difficult to shed.

"If you have an extended period of hot weather with warm night-time temperatures, then the temperature of a heavy concrete building will go up, and it will take one to two days for it to recover," says King Smith consulting engineers principal Professor Doug King.

All the while the building is too warm, energy will have to be used to cool it down. Effectively used, thermal mass can reduce cooling loads and, in some cases, remove the requirement to provide air-conditioning entirely. Since mechanical cooling is energy-intensive, this can have a significant effect on reducing CO_2 emissions.

"If all buildings being designed and built today undertook an overheating assessment using 2050 climate data, it is likely that some would overheat, or would need significant cooling," says Willmott Dixon principal consultant Steve Cook.

"Overheating and the need for thermal mass must be considered during design to provide the best solution, and this may include exposed soffits.

"From a value-engineering and resource efficiency point-of-view, making best use of thermal mass by leaving exposed concrete surfaces can be an added bonus in terms of programme and cost, by alleviating finishes such as false ceilings."

But recent research conducted by the BCSA and Tata Steel with 100 industry representatives revealed that only 9 per cent of respondents associated thermal mass with steel.

So for many projects seeking to use thermal mass, a steel-frame structure is not even considered as an option, even though it would deliver it – and may be quicker and more cost-effective.

"It's a common misconception that a building needs to have large volumes of concrete to achieve thermal mass"

EDWARD MURPHY, MOTT MACDONALD

CO-OPERATIVE HEADQUARTERS, MANCHESTER

In 2009, the Co-operative Group commissioned the construction of a 16-storey, 37,200 sq m headquarters in Manchester.

The building, which is scheduled for completion in September, provides 29,700 sq m of office space, combined with a restaurant, auditorium, car parking and bicycle spaces.

The client wanted the development to be a sustainable landmark and the first building in Manchester to achieve a BREEAM Outstanding rating.

To coordinate the structural engineering, architecture and building services, 3D BIM technology was used extensively. The software also provided energy models. Using the building's thermal mass formed a key part of the design response, with concrete soffits left exposed within the steel frame.

Buro Happold project engineer Paul Richardson says: "It's very much a bespoke design chosen to achieve the highest BREEAM rating, with an exposed soffit maximising the thermal mass.

"Steel was the natural choice for the framing material, as it gives us the large, column-free floor levels and the option for future flexibility."

The building is on target to achieve BREEAM Outstanding and Display Energy Certificate A rating, setting a benchmark for commercial office design.

CHESHIRE POLICE HEADQUARTERS, BLACON

Cheshire Police commissioned consultant Mott MacDonald and architect Fairhurst Design to create a 2,800 sq m headquarters in Blacon, Cheshire. This included office space for 120 staff, combat training spaces and a public enquiry area.

Sustainability and energy efficiency were key areas of focus for the design, but cost constraints and quick delivery were also important.

Mott MacDonald opted for a steel-framed building rather than a concrete-framed one to achieve a fast and cost-effective build.

The thermal mass of the structure was used to manage fluctuations in temperature in the building.

Mott MacDonald technical director Edward Murphy says: "It's a common misconception that a building needs to have large volumes of concrete to achieve thermal mass.

"In fact, the first 50 to 75 mm of an exposed concrete soffit is the bit that does all the work – the thickness of material exceeding this is thermally neutral in its beneficial effects on the space below.

"Thermal mass can, if designed correctly, be just as effective within an exposed hollow-core deck, steel-frame building as it can within a concrete frame. In this instance we chose to use a steel frame with hollow core deck because of the cost and time efficiencies this offered."

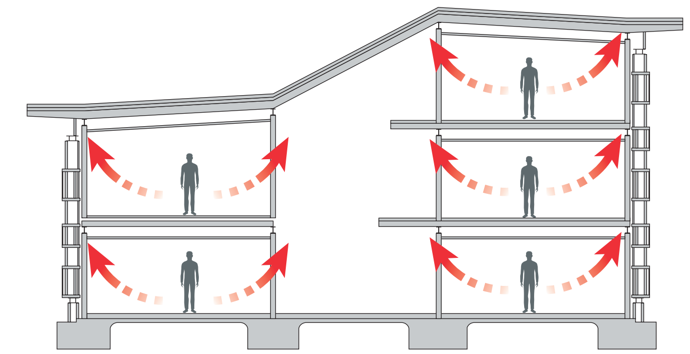
Using a steel frame rather than a concrete frame to achieve thermal mass saved approximately 5 per cent on the cost of the frame and four weeks in time, while still achieving best practice for energy use for this type of building.

FAST FACTS

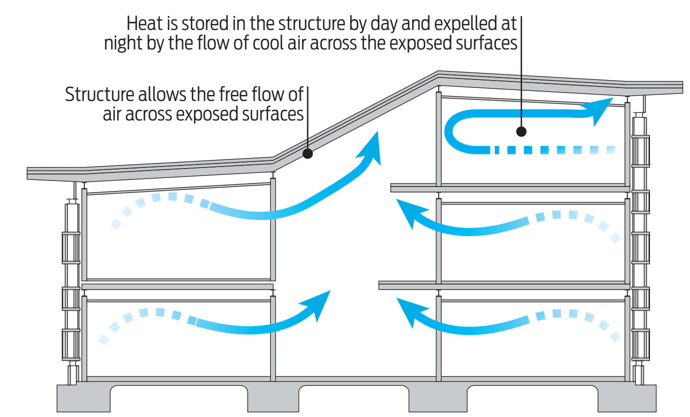
- Thermal mass is the ability of building materials to absorb heat, store it and release it at a later time
- Only the first 100 mm thickness of a concrete floor slab is required to optimise the thermal mass in a building
- Combining a steel frame with exposed concrete soffits can facilitate thermal mass while offering time and cost efficiencies
- Greater mass may be counterproductive and increases the carbon footprint of a building

For more information, see www.tatasteelconstruction.com/en/sustainability/thermalmass/

HOW DOES THERMAL MASS WORK?



During the day, solar gain, equipment-use and human activities generate heat, which warm the air in a building. The warmed air rises, flows across exposed surfaces and is absorbed into the fabric of a building



At night, cool air is allowed into the building and flows across surfaces which have been used to absorb heat during the day. These surfaces are then ready to absorb heat again the following day

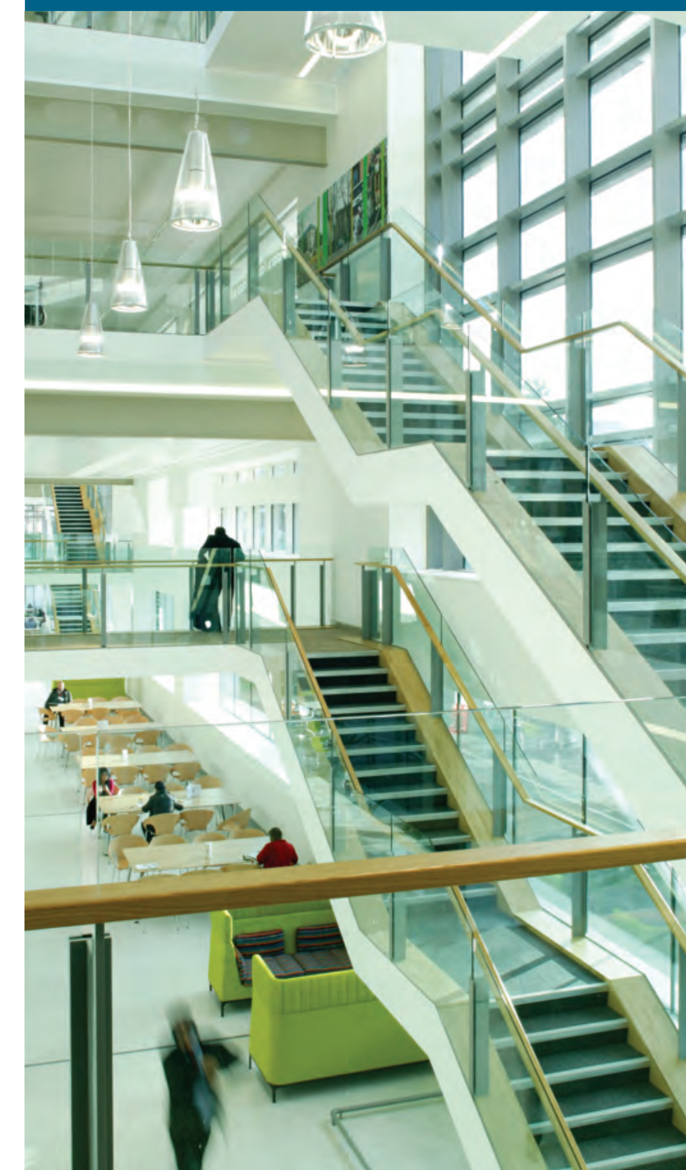
BIRMINGHAM CITY COUNCIL, ASTON

Birmingham City Council's £38 million Woodcock Street offices in Aston form part of an extensive office rationalisation and improvement programme, providing 22,000 sq m of accommodation over five floors for more than 3,000 employees.

The client wanted the development to be a flagship project to demonstrate excellent sustainability and collaborative working. Main contractor Thomas Vale and the project team needed to balance this aspiration with a challenging timescale.

Designing it as a steel-framed structure was deemed the only way the team could achieve the tight construction programme. Concrete floors were left exposed to use their thermal mass. This removed the need for excessive mechanical cooling in the building, offering significant cost and carbon savings. The project is expected to achieve a BREEAM Excellent rating.

By combining a steel frame with exposed concrete floors, the project team was able to deliver the project on time and on budget, while achieving around a 31 per cent reduction in CO_2 emissions compared with the minimum standards required for Building Regulations Part L compliance.



THOMAS VALE

A moment's success

A high-spec steel-framed office building at Regent's Place in central London has maximised its value by using an inventive approach to the structure's lateral stability system using a stiff moment frame structure

PROJECT REPORT
RUBY KITCHING

Project	North East Quadrant, Regent's Place, London
Client	British Land
Architect	Wilkinson Eyre
Construction manager	Lend Lease
Structural engineer	Halcrow Yolles
Steelwork contractor	William Hare

The North East Quadrant is the last area to be redeveloped in the 5 ha plot of land that makes up Regent's Place in central London. Currently under construction is an E-shaped steel-framed office block. The building has a common northern elevation from which three wings of varying heights project south.

The central block is 15 storeys tall and has a central atrium; the wing to the west is 10 storeys, and the east is eight. Client British Land has been developing the area for more than 20 years. This project was started at the beginning of 2010 and gained momentum when a major tenant was secured.

The site was formerly occupied by a 1960s office block with a single-storey basement. While its foundations could not be reused in the new development, its basement walls have been and form part of the new two-storey concrete basement.

"Since the office block was aimed at attracting multiple corporate tenants, long clear spans were required, so we went for a steel-framed solution with composite floors," says Halcrow Yolles project director Jason Guneratne. "To maximise the number of storeys for the height of the building, we used an integrated structure and services solution using cellular beams."

Each wing enjoys a great deal of natural daylight with the central block aided by an atrium. The blocks feature slipformed concrete cores for lateral stability and to accommodate lifts and stairs, but the core in the central block is located north of its most structurally efficient location.

> **"We managed to incorporate the moment frames sympathetically into the structure"**
> JASON GUNERATNE, HALCROW YOLLES

Core values

"Originally, the core was in the centre of the floor plate of the central building, similar to the other blocks, but it was moved towards the back of the building [north] to create more high grade office space," says Halcrow Yolles lead engineer Keith Davidson. "It meant we had to redesign the building because it changed its lateral stability system.

"The building was stable enough without the core at its centre, but we had to install a stiff moment-frame structure in the central block on the southern elevation, from level nine to the roof, to control the perception of inter-storey drift."

Essentially, since the two wings of the building terminate before level nine, the central block which continues six levels higher requires extra stiffening on the upper storeys.

"The fantastic thing was that we managed to incorporate the moment frames sympathetically into the structure so that from the outside, the framing system and views across London appeared unchanged from the original design," says Mr Guneratne.

Typically, cellular beams on the office floors are 650 mm deep with 400 mm openings for services. However, to allow light in through the glazing, the edge beams have been designed just 450 mm deep and are thicker sections as a result.

To create the stiffer moment frame, these edge beam sections had to be 100 mm deeper. In order to maintain the same edge/glazing detail, this extra 100 mm of steel section had to be buried into the concrete floor slab.

Design challenges continued up to the skewed ridgeline of the pitched roof. This level rises in height from 4 m at the eaves to 12 m at the apex, and also has to accommodate a track-mounted 40-tonne building maintenance unit. Again, a stiff moment frame using fabricated plate sections similar to the south elevation structure on the central block had to be designed, with some beams up to 800 kg/m.

With a tenant secured for the building, the client wanted the building to be ready as soon as possible. Mr Davidson says there was only six months between the appointment of the steel contractor to landing steel on site.

"Fortunately, the steel frame worked well in accommodating the core location change while keeping it on a fast-track construction programme," he says.

Since design drawings had to be turned around quickly, an engineer for steelwork contractor Hare was resident in Halcrow Yolles' office and, every week, meetings with project manager Lend Lease and architect Wilkinson Eyre ensured high-level decisions could be made so that design drawings could be signed off to allow fabrication to begin. Sign-off and fabrication were only a week apart for each floor going up the building.

365
Number of load-bearing columns

"We were able to significantly compress the design process by having sign-off meetings where everyone sat around a table making on-the-spot decisions," says Mr Davidson.

"We were able to make decisions at the meeting because we could visualise everything using Hare's 3D model – and we all put a lot of hard work into coming up with viable solutions."

Many of these decisions had to be made before the cladding and lift contractors were on board.

Model behaviour

Hare used 3D structural modelling which also included cladding features so that any clashes could be detected and acted upon before reaching site. "As we built up the model, we did virtual walk-throughs to assess how any changes had an impact on the structure," says William Hare London operations director Mark Smith.

Lend Lease project manager Adrian Richards adds: "As the design developed, we had a close relationship with the design team which allowed us to tackle the challenge of building the inclined columns and the complicated roof geometry."

Open sections are used for columns throughout the building except around the atrium and at ground level, where feature circular hollow section (CHS) columns 762 mm and 914 mm in diameter and 4.5 m or 9 m long are used.

But these actually conceal 365 columns that are the main load-bearing component – the CHS is merely an architectural shroud. To create these members, William Hare applied intumescent paint to each column before sliding it on a bogie through the steel tube.

Guide plates halfway along the tube ensured the column sections were straight, while end plates, each with H-shaped imprints capped over the ends of the tube, made sure columns stayed in place.

The building is made more dramatic by inclined columns in the atrium and along the south elevation, as well as the skewed, pitched roofs on each block.

"The four-degree incline of the ground floor columns had the potential to have an impact on the building from a lateral stability point of view," says Mr Davidson.

"However, on the south elevation, the columns lean out to the south and those in the atrium lean north, so they balance each other out to some extent."

The columns around the atrium had to be temporarily cross-braced or supported by temporary tension cables during construction, until the entire steelwork was in place. Only then could the temporary works be removed and the structure become self-supporting. The steelwork was coated offsite with intumescent paint at Hare's workshop in Scarborough to give a fire rating of 90 minutes.

"We value engineered the amount of paint required versus the material area of the cellular beams, and calculated the cost benefits of using heavier beam elements versus those of applying more paint and achieving lighter section weights," says Mr Smith.

The building is now structurally complete and on course to be ready for tenants in 2013.

CHS members contain internal load-bearing columns and are used to form the perimeter of the atrium

SCENIC LIFT ARMS

Fabricated tapered box section cantilevering arms connected to primary columns support the scenic lift guides.

"These were 700 mm-long exposed structural steel members which were also architectural features, so a lot of time was spent concealing connections inside them and welding on cover plates to a very high-quality finish," says William Hare London operations director Mark Smith.

"The challenge was to fabricate the box section while maintaining a route through for cabling."

The arms were welded into position and there was very little tolerance in the connections due to the accuracy of fit required for the lift to operate. Three slightly different arm designs were produced depending on the as-built site survey dimensions returned to Hare's workshop.

The price of frame

A new report comparing two different office blocks shows that the steel-framed option can be cheaper, quicker and greener than using concrete

COST
RUBY KITCHING

Research comparing the cost of building an office block using a steel frame with the cost of using a concrete one was commissioned by the British Constructional Steelwork Association and steel producer Tata Steel in November 2011.

Results of the independent study, carried out by quantity surveyor Gardiner & Theobald, consultant Peter Brett Associates (PBA) and main contractor Mace Group, have just been published.

The study looks at two different multi-storey building types – a three-storey business park office (Building 1) and an eight-storey city centre office (Building 2).

PBA designed the frames, G&T provided cost information and Mace considered buildability, logistics and programme. PBA also carried out an embodied carbon assessment for Building 2.

The study builds on previous comparison studies to reflect developments in construction techniques and market trends in different structural frame options.

"To have meaningful results, it was important that only really viable structural solutions were compared for each building type," says Tata Steel construction general manager Alan Todd. "This resulted in PBA developing four different designs for Building 1 and two for Building 2.

"The study also considers total building cost, not just structural frame cost, as the choice of structural frame material and configuration influences other parts of a building, such as the substructure, roof and external cladding." The report makes assumptions for appropriate finishes, fire protection, lateral stability, foundations and services.

The study also assessed the embodied carbon of construction and decommissioning of the city centre office block, where typically 99 per cent of steel and 82 per cent of reinforcement would be recycled and 100 per cent of concrete would be crushed to create granular fill at the end of the building's life.

"Current best practice for sustainability also considers replacement of Ordinary Portland Cement with fly ash and ground granulated blast furnace slag in concrete. This was included in the embodied carbon assessment for steel foundations," adds Mr Todd.

The study also considered the effect of using driven steel piles instead of concrete piles and pile caps in the embodied carbon assessment. "Driven steel piles are the sustainable option as they don't require excavation or disposal of soil, they have smaller pile caps and can be extracted for recycle or re-use when the building is decommissioned," says Mr Todd.

Study outcomes include:

- The total building cost for steel options are on average 5 per cent lower than concrete options as a result of lower floor and frame costs, smaller foundations, lightweight roofs, lower storey heights, reduced cladding costs and reduced preliminaries costs;
- Steel-framed options cost up to 9 per cent less than for concrete when the frame and upper floors alone were considered;
- Steel shortened construction programmes by 13 per cent compared with the concrete option for the out-of-town three-storey office and 11 per cent for the eight-storey city centre office;
- For the city centre office, the cellular steel option had 18-30 per cent lower embodied carbon than using post-tensioned band beam.

The full report is available at: www.steelconstruction.org

EMBODIED CARBON ASSESSMENT OF BUILDING 2

A cradle-to-grave assessment for emissions was made for the city centre office. This considered the embodied carbon of producing the framing material and frame elements, constructing the building and what happens to material when the building is decommissioned. It excluded emissions related to running the building.

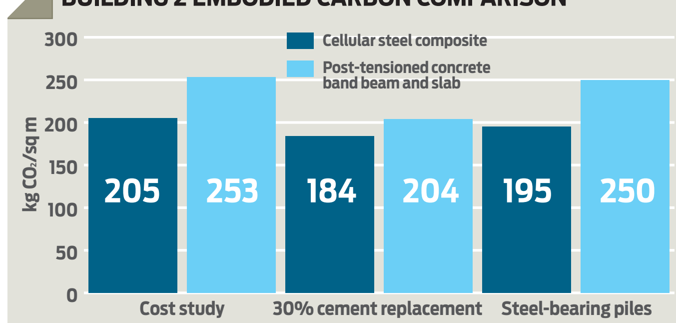
Industry data on materials' emissions was supplied from Target Zero publications for steel and from Concrete Centre publications for concrete. PBA initially assessed the buildings in line with the cost study and used Ordinary Portland Cement (OPC) for the concrete mix, which showed that the embodied carbon was 23 per cent lower for the steel frame than for the concrete frame.

The assessment was recalculated for best practice where 30 per cent of the primary sourced OPC was replaced with more sustainable fly ash and ground granulated blast furnace slag. This reduced the embodied carbon of both framing options, but the steel composite option still had around 11 per cent less embodied carbon.

Adopting driven steel piles for each option was also considered as a more sustainable alternative to concrete continuous flight auger piled foundations. This resulted in longer piles for both options, which was reflected in a rise in foundation costs. However, these were offset partly by a faster substructure construction programme.

Across the whole building, the embodied carbon was reduced to 195 kg CO_2/sq m for the steel option and to 250 kg CO_2/sq m for the post-tensioned concrete option.

BUILDING 2 EMBODIED CARBON COMPARISON



SOURCE: GARDINER & THEOBALD

BUILDING 1 – THREE-STOREY BUSINESS PARK OFFICE

This out-of-town rectangular building has a gross internal area of 3,200 sq m with an 18 m-deep floor plate and structural grid of 7.5 m x 9 m with a central core. Its external envelope of brick outer-skin has an allowance for windows at 35 per cent of the façade area.

Four viable framing solutions were developed by PBA:

- Steel composite beams and composite slab
- Steel frame and precast concrete slabs
- Reinforced concrete flat slab
- In-situ concrete frame with post-tensioned slab

The study concluded that the two steel design solutions were cheaper to build than either of the concrete ones because of the shorter construction period for the steel frame and its foundations.

With a steel frame being lighter than the concrete frame, the foundations were simpler and hence quicker to build. It also reported that the steel composite beam and slab frame solution had the lowest frame and floor cost as well as overall building cost (see Building 1 table).

Comparison of the construction programme for each of the four framing solutions offers an insight into which activities took longer to complete, resulting in a longer overall build time.

In the case of the steel options, both took 45 to 47 weeks to construct, with the steel composite solution being quickest due to the speed in laying and distributing the steel decks, which allowed follow-on trades to begin working earlier.

Summary

- The frame and floor cost for the steel-framed options are up to 10 per cent lower than for the concrete option and overall building cost is up to 6 per cent lower than for concrete;
- Both steel-framed options can be built more than 5 per cent quicker on average than the concrete options.

COSTS FOR BUILDING 2 (BELOW) – CITY CENTRE OFFICE BLOCK

Expressed in £/sq m gross internal floor area

	Steel cellular composite	Post-tensioned concrete band beam and slab
Substructure	£56	£60
Frame & upper floors	£194	£210
Total building	**£1,861**	**£1,922**

SOURCE: GARDINER & THEOBALD

COSTS FOR BUILDING 1 (ABOVE) – OUT OF TOWN OFFICE BLOCK

Expressed in £/sq m gross internal floor area

	Steel composite	Steel + precast concrete slabs	Reinforced concrete flat slab	Post-tensioned concrete flat slab
Substructure	£52	£55	£67	£62
Frame & upper floors	£140	£151	£155	£150
Total building	**£1,535**	**£1,561**	**£1,631**	**£1,610**

SOURCE: GARDINER & THEOBALD

BUILDING 2 – EIGHT-STOREY CITY CENTRE OFFICE

This building has a gross internal area of 16,500 sq m with a 7.5 m x 15 m structural grid and double height reception area. The external envelope is a unitised curtain wall system.

Two viable framing solutions were developed by PBA:

- Cellular composite beams and composite slab (steel composite option);
- Post-tensioned band beams and slab with insitu columns (post-tensioned concrete option).

The study concluded that the steel composite option had both a lower frame and floor cost and lower total building cost than the post-tensioned concrete band beam option.

The steel composite option also had a lower floor-to-floor height, resulting in a 5 per cent smaller external envelope and reduced cladding cost. G&T's programme study revealed the steel composite option cut the construction programme by 12 weeks for the frame and by eight weeks for the overall build programme compared with the post-tensioned concrete option.

The frame and floor cost of the steel composite option is more than 8 per cent lower and the overall building cost up to 3 per cent lower than the post-tensioned concrete option.