STEEL INSIGHT #18

COST UPDATE AND CASE STUDIES

STEEL INSIGHT

The latest article in the series provides an update from Gardiner & Theobald on construction costs, an interview with David Moore, BCSA's Director of Engineering on steel's performance in fire situations, while overleaf are case studies of two single storey steel structures.

COST MODEL UPDATE

Steel Insight 3 "Cost Comparison study" (April 2012) analysed two typical commercial buildings to provide cost and programme guidance when considering available options during the design and selection of a structural frame.

Building 1 is a typical out-of-town speculative three-storey business park office with a gross internal floor area of 3,200m² and rectangular open plan floor space. Cost models were produced for four frame types developed by Peter Brett Associates to reflect the typical available framing options: steel composite, steel and precast concrete slab, reinforced concrete flat slab and post-tensioned concrete flat slab.

Building 2 is an L-shaped eight-storey speculative city centre office building with a gross internal floor area of 16,500m² and a 7.5m x 15m grid. Cost models were developed for a steel cellular composite frame and post-tensioned concrete band beam and slab, being two frame and upper floor types that could economically achieve the required span and building form.

The cost models for Building 1 and Building 2 are regularly updated by G&T, and the latest data for Q3 2016 is presented here.

As Figure 1 shows, the steel composite beam and slab option remains the most competitive for Building 1, with comparable frame and upper floors cost and the lowest total building cost.

For Building 2 (Figure 2), the cellular steel composite option has both a lower frame and upper floors cost and a lower total building cost than the post-tensioned concrete band beam option, with lower substructure costs, lower roof costs and a lower floor-to-floor height, resulting in lower external envelope costs.

The tender price increases seen in Q3 2016 are reflected in the updated indicative cost ranges shown in the structural steel frame cost table (Figure 3). Costs reflect 3Q 2016 pricing as of the end of September 2016. To date, limited impact on prices has been seen following the EU referendum result, except the weakening of the pound against the euro. No allowance has been made for impacts of the EU vote on price and currency fluctuations beyond end September 2016.

To use the table: a) Identify which frame type most closely relates to the proposed project, b) Select and add the preferred floor type, c) Add fire protection if required, d) adjust the total according to the BCIS location factor (Figure 4).

Before using such standard ranges it is important to confirm the anticipated frame weight and variables such as the floor-to-floor heights to determine whether they are above or below the average and to adjust the rate used accordingly.

Figure 1: Building 1 Cost Model (key costs per m² Gross Internal Floor Area (GIFA), Central London location)

	Steel composite	Steel and precast concrete slabs	Reinforced concrete flat slab	Post-tensioned concrete flat slab
Substructure	£71	£75	£91	£85
Frame and upper floors	£177	£196	£173	£205
Total building	**£1,982**	**£2,099**	**£2,183**	**£2,165**

Figure 2: Building 2 Cost Model (key costs per m² GIFA, Central London location)

	Steel cellular composite	Post-tensioned concrete band beam and slab
Substructure	£80	£86
Frame and upper floors	£244	£281
Total building	**£2,461**	**£2,565**

Figure 3: Indicative cost ranges based on GIFA (Q3 2016)

TYPE	GIFA Rate (£) BCIS Index 100
Frame 1 - low rise, short spans, repetitive grid / sections, easy access	120 - 150/m²
Frame 2 - high rise, long spans, easy access, repetitive grid	170 - 200/m²
Frame 3 - high rise, long spans, complex access, irregular grid, complex elements	205 - 235/m²
Floor - metal decking and lightweight concrete topping	55 - 70/m²
Floor – precast concrete composite floor and topping	65 - 85/m²
Fire protection (60 min resistance)	17 – 26/m²
Portal frames – low eaves (6-8m)	62 - 82/m²
Portal frames – high eaves (10-13m)	78 - 103/m²

Figure 4: BCIS location factors, as 16 September 2016 (UK mean = 100)

Location	BCIS Index	Location	BCIS Index
Central London	124	Leeds	92
Nottingham	93	Newcastle	95
Birmingham	99	Glasgow	96
Manchester	101	Belfast	62
Liverpool	96	Cardiff	92

This and the previous Steel Insight articles produced by Rachel Collins (Partner) and Alastair Wolstenholme (Partner) of Gardiner & Theobald are available at www.steelconstruction.info

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DOUSING FIRE MYTHS

● While structural steel performs best in fires, the sector continues to make advances in improving the material's resistance to fire. Will Mann reports

"Some might be surprised that out of all framing materials, steel performs best in fire," says Dr David Moore, director of engineering at the British Constructional Steelwork Association (BCSA).

Unprotected structural steel only begins to loose strength at temperatures about 400ºC and at 500ºC it has 78% of its strength at ambient temperature. The last time that happened in the UK was in 1990, when a fire broke out in a part completed 14-storey building at Broadgate in the City of London. Despite temperatures reaching 1,000°C, no columns, beams or floors in the steel structure collapsed.

Following this, the steel sector decided to invest in extensive fire research. Recent work includes continued investigation into steel's performance in fires, advances in fire engineering, and improvements in fire protection coating technology.

"Fire remains an important issue for the BCSA," says Moore, who was part of an extensive BRE and the steel industry fire research programme which ran through the 1990s and early 2000s.

"There are two important points to make," he says. "Firstly, the standard fire test – which was used in the BRE research – takes place in an approved furnace, and is based on a fire that burns forever, getting hotter and hotter, which doesn't happen in reality. And secondly, the amount of material in a typical building that can burn means the fire will rarely reach extreme temperatures."

Structural fire resistance requirements are set out in the Building Regulations (*see box*).

"They do not tell you how to make a building safe from fire, but what they do tell you are the minimum periods for fire resistance," says Moore. "With a skyscraper, it will obviously take longer to evacuate the building, so up to 2 hours of fire resistance is necessary.

"Whereas for certain open sided car parks it is just 15 minutes.

"The fire resistance of steel-framed buildings is partly due to the material itself, but also due to secondary effects, such as tensile membrane action in composite floors."

Tensile membrane action occurs in composite floor slabs when the horizontal supporting beams lose strength and deflect, as may happen in a fire at high temperatures. In such a scenario, the mechanism by which the slab resists the applied loads changes from bending resistance to tensile membrane action.

Fire engineering

"The BRE tests showed that composite steel deck floors have resistance to fire far greater than was indicated by standard fire tests on single beams or slabs," says Moore. "The implication of this is that not every single steel section in a building needs protection."

This kind of thinking is now often employed in fire engineering.

"On a particularly large building, saving the need for protective coatings on all the steelwork can have a major saving on costs, both in construction and maintenance," he adds.

One example is the 242m Heron Tower in London (pictured). Arup's engineered fire protection layout reduced fire protection to all primary members from two hours to 90 minutes and left secondary beams unprotected, because the structural form was purposely designed to be robust if exposed to fire.

Protective coatings on the actual members is the last line of fire defence for structural steel buildings.

Passive fire protection materials can be divided into two types. Non-reactive, of which the most common types are plasterboards and sprays, insulate steel beams against the effects of the fire. However, increasingly popular are reactive coatings, such as intumescent paint. Under extreme temperatures – typically 200-250°C – they swell and provide an expanded layer of insulation for the steel.

"The advantage of intumescent paint is that it can be put on in the workshop, so it takes a trade off site and saves on cost and programme, and also it can provide a decorative finish."

"Coating technology advances every year," Moore adds. "Fire protection manufacturers aim to make it possible to apply the paint rapidly and for it to dry rapidly, and not chip off on site," he says.

The thickness of the protective coating depends on the level of resistance needed. "On certain tall buildings, the fire resistance can be up to 120mins." says Moore. "However, as the Heron example shows, fire engineering can mean considerably less coating is needed."

The Building Regulations, fire, and steel-framed buildings

The Building Regulations for England and Wales state: "The building shall be designed and constructed so that, in the event of a fire, its stability will be maintained for a reasonable period."

Guidance is also provided on the level of structural fire resistance required. This is usually measured in terms of the ability of the building's structural section to survive in a standard fire test. For example, an office building more than 30m in height requires 120min fire resistance plus a life safety sprinkler system. An unsprinklered building 18-30m tall requires 90min fire resistance.

Slightly different regulations apply in Scotland and Northern Ireland and some local and building specific regulations are also in place.

All the government documents make provision for fire safety engineering approaches to building design. The Regulations state: "Fire safety engineering can provide an alternative approach to fire safety."

The world's first design code for steel in fire, BS5950 Part 8, was published in the UK in 1990 and redrafted in 2003, after tests by BRE and the steel industry. In 2008, BS 9999 was published to provide a more flexible approach to fire safety design, and offer more economical, engineered solutions than may be possible using the government publications.

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SPONSORED FEATURE

SIEMENS MANUFACTURING FACILITY, HULL

A new wind turbine manufacturing facility in Hull required some heavy-duty steelwork to accommodate its huge cranes. Will Mann reports.

Green Port Hull is an ambitious project that aims to make the city of Hull and the Humber a global centre for renewable energy, taking advantage of its proximity to North Sea offshore wind farms.

At the heart of this vision is a new wind turbine blade plant being developed by Siemens. With partner Associated British Ports, the energy giant is investing £310m in manufacturing, assembly, logistics and servicing facilities at Hull's Alexandra Dock.

The 40,000m² factory will mould turbine blades 75m long – the world's longest. Additionally, the site will store the blades ahead of delivery to their offshore destination, along with the nacelles – the fuselage containing the generating components that the blades connect to – and the masts.

Given the size of the turbine blades – not to mention the size of the cranes used in the manufacturing process – the scale of the Siemens facility is substantial. The steel-framed multi-span braced structure measures 300m long by 116m across. The biggest spans are 47m, and the roof's maximum height extends to 15m.

"The design of the steel frame has been very much driven by the requirements of the manufacturing process," says Mark Billington, regional director with engineering consultants Waterman Structures.

Prior to main contractor VolkerFitzpatrick starting work on the plant, the site had to be raised 200mm above the flood plain, and a 1m-deep stone plateau constructed. Additionally 4,000 driven piles were installed as part of the groundworks.

The building itself is split into two main sections. The northern section, which houses the manufacturing and painting, has four spans: two 36m-wide spans each containing manufacturing and moulding lines; a

THE DESIGN OF THE STEEL FRAME HAS BEEN VERY MUCH DRIVEN BY THE REQUIREMENTS OF THE MANUFACTURING PROCESS

MARK BILLINGTON, WATERMAN STRUCTURES

22 m-wide painting span between; and, attached along the eastern side of the building, a 22 m-wide span to accommodate storage and warehousing. The southern section is a finishing area with three spans.

The northern section is where the roof is highest, reaching 15m to the eaves, because of the need to accommodate the cranes, the biggest of which have a 40t-capacity. This was one of the most challenging aspects of the steelwork design, says Billington.

"As industrial cranes go, these are very big," he says. "The spans are formed by twin-braced lattice columns supporting roof trusses that measure up to 2.1m deep because of the size of the cranes."

There are overhead cranes in all the production bays, which run across the spans on rails, while smaller console cranes run on steel support rails underneath.

The crane movement was also a concern for both the design engineer and steelwork contractor Caunton Engineering.

"With cranes, there are obviously vertical and horizontal loads to consider; the gantry has to accommodate biaxial loading," says Billington. "At tender stage, we designed a traditional I-beam for the vertical loads, with a channel welded into the side of the I beam for the horizontal loads. However, Caunton Engineering was concerned about welding the channel into the I-beam, because of the size of the loads. So we changed the design and, instead, the I beam connects to a heavy steel plate."

Worries about fatigue

Another area of concern was the connection between the crane girders and the columns, says Billington. "It is a common area for fatigue because of the cyclic loading condition created by the crane movement, and the changes in stress," he says. "The fatigue zeroes in on sharp corners and stress concentrations in the structure. So the detailing in the connection from Caunton Engineering had to be spot on."

The southern section of the facility – the finishing area – has no cranes, so the roof level here drops to 10m. It is as wide as the northern section, but is formed from three spans, two at 47m and a third measuring 22m. With no cranes to support, the truss-supporting columns are 610 UBs rather than twin lattice sections.

The longest trusses were brought to Alexandra Dock in three sections, while the 22 m-long trusses were made in two parts and bolted together on-site. Up to five mobile cranes were used for the steel erection.

The envelope of the facility is a combination of precast concrete panels up to 2.4 m and composite cladding to roof level. An unusual feature of the envelope is that the cladding is horizontally spanning because the building does not have sheeting rails.

"The crane columns have been created by turning a pair of I-beams round from their normal orientation – due to the size of the cranes – which means that the outer face of the steelwork is not a single plane," says Billington. "So instead of using sheeting rails, additional vertical sections of steel were added to form the cladding connections."

The Siemens development includes a two-storey office block adjoining the manufacturing plant, also steel-framed. It is structurally independent, however, with stability coming from a series of moment frames.

"It features 'slim floor' construction, where precast concrete planks are supported by plates attached to the undersides of the steel members, allowing the slabs to sit within the depth of the beams," says Billington.

VolkerFitzpatrick is due to complete the project this autumn. The first blades to be manufactured by the new Siemens facility are set to leave the site by year-end.

PROJECT TEAM

CLIENT: Siemens

ARCHITECT:
Pringle Brandon Perkins+Will

MAIN CONTRACTOR:
VolkerFitzpatrick

STRUCTURAL ENGINEER:
Waterman Structures

STEELWORK CONTRACTOR:
Caunton Engineering

THE MET OFFICE BUILDING, EXETER

A complex steel frame is being constructed on Exeter Science Park for a new Met Office facility that will accommodate a powerful new supercomputer. Will Mann reports.

The Met Office's new facility at Exeter Science Park will house one of the world's most powerful supercomputers and, in keeping with the technology, the site has a futuristic look about it.

The complex comprises two separate buildings, one of which has an unusual, hexagonal shape – a design "inspired by the movie Tron" according to architect Atkins.

Willmott Dixon was awarded the £20m construction contract and began work in September 2015. The project is on a greenfield site on the outskirts of Devon's county town, close to the Met Office headquarters.

The supercomputer itself will cost £97m, and the Met Office says it will make the UK a world leader in weather and climate prediction. Weighing 140t, it will be able to perform more than 16,000 trillion calculations per second, and will be 13 times more powerful than the Met Office's current system.

The computer will be housed in one of the two structures, known as the IT Hall. It is a single storey, portal-framed steel structure, 90m long by 25m wide, and with a 15m-wide central column-free hall to accommodate the computer.

However, it is the adjacent Collaboration Space, a two-storey office building, which is the most challenging from a design engineering perspective. This complicated steel structure leans in two directions, and requires sophisticated stability systems to resist the forces generated by its angular design.

Although steel might have seemed an obvious choice for the framing material, the design has been through a series of iterations.

"Throughout the design process, a variety of materials were considered for both buildings," WSP Parsons Brinckerhoff associate director Ian Branch says. "The choice of steel was made primarily to suit the challenging programme requirements."

BIM modelling was central to the design of both structures, and particularly the Collaboration Space.

Kristian Cartwright, Willmott Dixon's project manager, says: "The project architect (Atkins) managed the BIM model, which was kept in a common data environment throughout, with components from different packages successively added as we built up the model.

"We worked closely with our M&E contractor NG Bailey to run the ductwork between the steel members of the frame, while the steelwork contractor William Haley Engineering used the BIM environment to schedule deliveries of the steelwork and programme the erection."

The groundworks phase comprised installation of pad and strip foundations before the steelwork contractor started on site.

The steel programme began with the IT Hall frame, chiefly because it will house the supercomputer and needed to be completed first. It was also relatively straightforward and was erected in just three weeks, using a 50t-capacity mobile crane.

> IT WAS A DIFFICULT SHAPED BUILDING TO WORK WITH AND OUR ENVELOPE SUBCONTRACTORS USED THE BIM MODEL TO HELP US UNDERSTAND WHERE THERE WERE CLASHES
>
> KRISTIAN CARTWRIGHT, WILLMOTT DIXON

"To help accelerate the IT Hall programme, we adjusted the portal sizes slightly, so that the precast floor slabs could 'fly through' the frame and be installed more quickly," says Cartwright.

The propped portal frame's sloping sides are formed with raking columns. Two rows of internal columns create the 15m spans for the computer hall, while two outer 5m spans accommodate ancillary spaces. The IT

How the completed Met Office site will look and (below) stages in the construction of the collaboration hall

Hall building also includes a huge services package, designed and installed by M&E subcontractor NG Bailey, to support the computer.

The more complex Collaboration Space structure is formed around a two-storey internal steel frame, which uses a 7.2m by 4.8m grid. This box was erected first and initially stabilised by temporary bracing.

The two sloping elevations, built out from the internal box, are formed from CHS columns set at an angle of 60 degrees. The front elevation slopes inwards while the back elevation inclines in the opposite direction. Both elevations use tubular steelwork for aesthetic reasons as the columns will be left fully exposed behind glazed facades.

The Collaboration Space also features folded ends, formed by two further rows of raking CHS columns. The members in the bottom row slope outwards, while the top row slopes inwards, and a central bolted connection holds the 'fold' shape in position. These columns were all designed as moment frames.

The structure will be completed by construction of a concrete lift shaft, together with moment frames and braced bays, providing stability after the temporary bracing from the internal steel box is removed.

The Collaboration Space will be wrapped in glazing, curtain walling and zinc cladding. Installation of these packages was also aided by the 3D model.

"It was a difficult shaped building to work with and our envelope subcontractors used the BIM model to help us understand where there were clashes and how to position the purlins and the mullions," Cartwright says.

The Met Office supercomputer facility is being installed in three phases, with the final phase due to be completed in Spring 2017. As well as helping to improve weather predictions, the computer is intended to be a catalyst for further growth on the Exeter Science Park, supporting collaboration and partnerships between science, business and academia.

PROJECT TEAM

CLIENT: The Met Office
ARCHITECT: Stride Treglown
PROJECT ARCHITECT: Atkins
MAIN CONTRACTOR: Willmott Dixon
STRUCTURAL ENGINEER: WSP Parsons Brinkerhoff
STEELWORK CONTRACTOR: William Haley Engineering