STEEL INSIGHT

MULTI-STOREY OFFICES

The third of the Steel Insight series looks at structural solutions for office buildings, and how steel can provide advantages in terms of cost, programme time and sustainability

01 | Introduction and overview of the study

In November 2011 the BCSA and Tata Steel commissioned Gardiner & Theobald (G&T), Peter Brett Associates (PBA) and Mace Group to undertake an impartial study of current construction practice for multi-storey offices to provide cost and programme guidance for quantity surveyors and design teams.

The study builds on previous comparisons to reflect developments in construction techniques and changes in prevalence of different structural frame solutions.

As decisions on frame material and configuration will be based on a number of factors, not simply cost, the study also considered the programme and buildability implications for each option and embodied carbon impacts for Building 2.

PBA identified and designed representative framing solutions for two typical office buildings – a business park office (Building 1) and a city centre office (Building 2). G&T provided cost information for each frame option and Mace considered buildability, logistics and programme. PBA also carried out the cradle to grave embodied carbon assessment on Building 2.

The objective of the study is to provide a comprehensive comparison of two typical office buildings across a number of aspects for different structural solutions. The configuration and design of the office buildings is based on the design team's experience of current practice to provide an impartial comparison that could be used by others when considering the options available during the design and selection of a structural frame.

02 | Building 1 – Typical business park office building

Building 1 is a typical speculative three-storey business park office building with a gross internal area of around 3,200m².

It is typical of a low rise building in an out of town location and is rectangular with a floor plate width of 18m to give an open plan space.

The clear floor-to-ceiling height has been set at 2.8m and the building contains one central core, 2nr lifts and an external metal escape stair. The external envelope has been assumed to be brick outer skin construction supported by a steel angle off the slab edge with an inner leaf of cold rolled metal studwork built directly off the slab, with an allowance for windows at 35% of the facade area.

The building has been assumed to have mixed mode ventilation and the floor-to-floor heights include for a 150mm ceiling and lighting zone and a 150mm raised floor zone.

An architect's impression and indicative cutaway, produced by Make Architects, are shown above and right.

PBA established the structural grid at 7.5m x 9m based on an optimum grid for a typical business park office not dictated by site constraints and this was used for all frame types, which consisted of the following four options:

1) Steel composite beams and composite slab
2) Steel frame and precast concrete slabs
3) Reinforced concrete flat slab
4) In situ concrete frame with post tensioned slab

For all options the foundations have been designed as unreinforced mass concrete pads, the core construction is steelwork cross braced framing with a medium density blockwork infill for the steel options and concrete shear walls for the concrete options.

For both steel options, the 30 minute fire resistance is provided through intumescent coating to beams and bracing members and boarding to columns, while for the concrete options, it is assumed that the internal columns are plastered and painted for aesthetic purposes.

Allowances have been made for all options for a part open and part enclosed roof plant area and lift motor room. In terms of roof construction, the two steel framed options have a lightweight steel deck roof, while the concrete options continue the concrete slab construction of the lower floors.

The floor-to-floor heights for the steel options include an 800mm service zone below the metal deck (300mm clear beneath the beams) and the concrete options allow for a 600mm services zone beneath the slab.

03 | Building 1 – Cost comparison

Gardiner & Theobald provided the costs for the study, based on market testing and recently tendered projects. Costs are all at Q1 2012 prices, exclude fees, VAT, project contingency and furniture, fixtures and equipment/AV allowances etc and are based on construction in the City of London to enable direct comparison with Building 2; however they can be adjusted for different locations using BCIS location factors (Figure 7).

The study recognises the importance of considering all elements of the total building cost, not simply the cost of the structure as some elements are affected more by the choice of structural frame than others. As such, the study considered whole building cost rather than just structural frame cost. The substructure, roof and external cladding costs were assessed for each option rather than including constants across all options.

The key costs for Building 1 expressed as a cost per m² gross internal floor area (GIFA) are shown below (Figure 1).

The impact of construction programme for each option has been considered in the total building costs, with the steel options benefitting from lower preliminaries costs due to their shorter construction programmes (as reviewed in detail overleaf).

The steel composite beam and slab option has both the lowest frame and upper floors cost and lowest total building cost. This option has the lowest substructure costs of all frame options due to the lighter frame weight and the lowest roof cost due to the lightweight steel roof deck. The structural zone and floor-to-floor height, while not the lowest of all the options, does not result in elevated cladding costs as only the concrete post tensioned flat slab option has a notably lower floor-to-floor height and therefore reduced area of cladding.

Conversely, the reinforced concrete flat slab option has both the highest frame and upper floors cost and highest overall building cost. The frame and floors cost is over 10% higher than the steel composite and the total building cost is about 6% higher. This option has the highest substructure costs due to the heavier frame weight, the highest roof and preliminaries costs due to the longest programme.

A review of the steel and precast concrete slab and post tensioned flat slab concrete options also highlights the importance of considering total building cost rather than just frame and floor costs when analysing and selecting the structural frame material during the design stages. The post tensioned option has a marginally lower frame and floor cost than the steel and precast option (£150/m² compared with £151/m²), however on a total building basis, the steel and precast slab option has a lower cost (£1,561/m² compared with £1,610m²), due to both a lower roof cost and lower preliminaries resulting from the shorter programme.

Therefore, on comparison of all four options, it is evident that on a like for like basis the steel composite beam and slab frame has the lowest frame and floor and overall building cost, followed by the steel and precast concrete floor slab option with the two concrete options being higher.

FIGURE 1: COSTS FOR BUILDING 1 BASED ON GROSS INTERNAL FLOOR AREA (GIFA)

	Steel Composite	Steel and Precast Concrete Slabs	Reinforced Concrete Flat Slab	Post Tensioned Concrete Flat Slab
Substructure	£52/m² GIFA	£55/m² GIFA	£67/m² GIFA	£62/m² GIFA
Frame and Upper Floors	£140/m² GIFA	£151/m² GIFA	£155/m² GIFA	£150/m² GIFA
Total Building	£1,535/m² GIFA	£1,561/m² GIFA	£1,631/m² GIFA	£1,610/m² GIFA

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04 | Building 1 – Programme comparison

Cost is undoubtedly a key driver in decision making when comparing alternative frame materials and configurations. However for many projects, the comparative programme and buildability impacts are arguably as important and should also be considered when selecting the frame material.

Mace undertook the programming analysis for each option and to ensure a robust comparison, preceding and succeeding trades to the frame elements were included to ensure a holistic approach to the study.

The programme durations for construction of the ground floor slab (two weeks four days), external facade (15 weeks) and internal works to a CAT A finish (18 weeks per floor) were assumed to be the same in overall duration for each option. The study assumes that the internal fit out commences on the ground floor and progresses up the building with a lag of three weeks between the commencement of the next floor, giving an overall duration of 24 weeks for each option.

The substructure duration was also considered in detail for each option. Both steel options required nine weeks due to the similar quantity of work, however longer durations of 10 weeks three days for the reinforced concrete flat slab and 10 weeks for the post tensioned option were required to reflect the higher volume of groundworks.

The programmes for the frame and upper floor construction are similar for both steel options. The precast slab requires slightly larger foundations than the composite option, but this is largely offset by the reduced number of steel members in the precast option, giving an overall very similar programme.

Likewise, it is quicker to lay the steel decking for the steel composite option due to the ability to load out multiple numbers of decks at any time while the precast planks are limited to one per lift, but this time advantage is offset due to the time required to stud weld each of the decks, which is a slower process than grout filling between the precast planks and both then require a concrete topping.

Ultimately, the advantages and disadvantages of each steel option largely cancel each other out providing very similar programme periods for both the frame and overall construction. The steel composite option however, due to the speed of laying and distributing the steel decks provides the quickest frame and overall duration by one week.

The programmes for the frame and upper floor construction are also similar for both concrete options as the processes involved in constructing the structure are fundamentally the same. The main variant is within the slab construction, with the post tensioned option providing a slightly quicker duration overall due to the lower quantity of reinforcement to place. The foundations duration for the post tensioned option is also quicker as the structure is lighter and therefore the extent of excavation and concrete pouring to the foundations is less.

Of all four options, the steel composite frame provides the fastest method of frame construction and overall programme for Building 1.

05 | Building 1 – Logistics and buildability

To inform the programmes, Mace undertook a logistics analysis for each of the frame options and this has been reflected in total building costs through the preliminaries analysis.

For both steel options, construction is assumed to be phased, with the excavation, foundations, drainage and service ducts, ground floor slab and erection of the steel frame and steel or precast decks occurring in four phases. A single mobile crane (about 50 tonnes) is used for material distribution and loading as full perimeter access to the building is available and the placing of concrete or structural screed to floors would utilise a concrete pump.

For both concrete options, construction is assumed to occur across two zones, each consisting of three phases. The sequence includes the excavation, concrete foundations, drainage and service ducts, ground floor slab, reinforced concrete columns, formwork and propping for slabs, reinforcement of post tensioned strands and placing of insitu concrete slabs using a concrete pump. A tower crane located centrally on the building perimeter is assumed to be the most productive means of material distribution as material can then be distributed between both construction zones. The cost of the tower crane base has been included in the preliminaries costs however it should be noted that there may be oversailing issues with a saddle jib crane.

06 | Building 1 – Summary

The cost and programme analysis of all four frame options for Building 1 has shown that the steel composite beam and floor option has both the lowest cost and the shortest programme, followed by the steel and precast concrete floor slab option.

The frame and floor cost for the steel framed options are up to 10% lower than for concrete and the overall building cost is up to 6% lower than for concrete. Even taking an average of the two steel options and an average of the two concrete options, the steel option costs are over 4% lower for both frame cost and total building cost.

Furthermore, both steel framed options can also be constructed in a shorter time frame than for the concrete buildings, on average over 5% quicker.

07 | Building 2 – Typical city centre office building

Building 2 is a typical eight-storey speculative city centre office building with a gross internal area of around 16,500m². It is L-shaped with a double height reception area, central core and internal secondary escape stair. The clear floor-to-ceiling height has been set at 3m.

The external envelope is a unitised curtain wall system constructed in storey height panels 1.5m wide with feature fins/solar control. Solid areas are lined with cold rolled metal studwork, insulation and plasterboard.

The building has been assumed to have four pipe fan coil air conditioning without natural ventilation.

An architect's impression and indicative cutaway, produced by Make Architects, are shown above and overleaf.

PBA established the structural grid at 7.5m x 15m based on experience of similar city centre schemes, and this was used for both of the following frame options:

1) Cellular composite beams and composite slab
2) Post tensioned band beams and slab, in situ columns

Both options adopt CFA piles and there are typically three to four piles per column pile cap. The core construction is steel cross braced framing with a medium density blockwork infill for the steel option and concrete shear walls for the concrete option.

It is noted that buildings of this type would normally include a basement; however for continuity between the options, the buildings are assumed structurally to start from ground floor with no impact from any basement construction as the basement will be the same construction for all options.

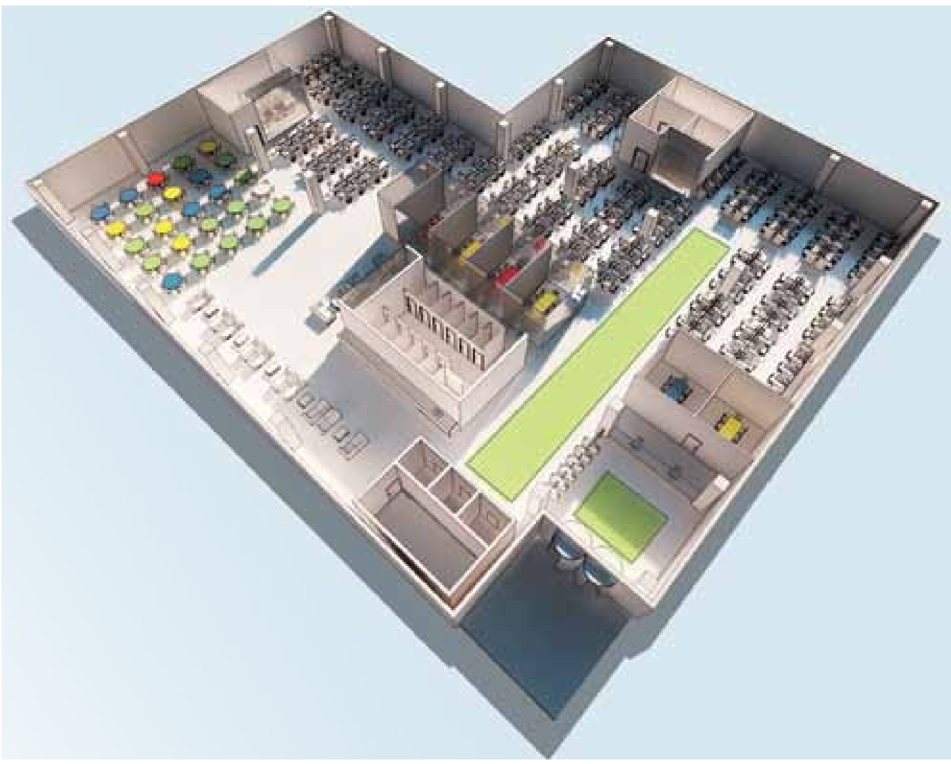
The 60 minute fire resistance is provided to the steel framed option through intumescent coating to beams and bracing members and boarding to columns, while the internal columns of the concrete option are plastered and painted for aesthetic reasons.

Allowances have been made to both options for a part open and part enclosed roof plant area and lift motor room. The plant area is a fabricated steelwork portal frame with composite metal panel cladding and the roof decks for both options continue the floor construction of the lower floors.

The overall floor-to-floor height for the steel option is 4.18m, which includes a 700mm zone for services distribution through the beams with 400mm diameter holes allowed at 600mm centres.

The overall floor-to-floor height for the concrete option is 4.375m, which includes a 475mm clear zone below the concrete band beams for services distribution.

Both options also include allowances within the floor-to-floor heights for a 150mm ceiling and lighting zone and a 200mm raised floor zone.



08 | Building 2 – Cost comparison

The Building 2 cost study also considered whole building cost alongside frame and floor costs, with the substructure, roof and external envelope reviewed in detail, however basement costs have been excluded from the study. As the frame material choice also impacts on programme, the results of the Mace programme and logistics analysis were also included when determining preliminaries costs.

All costs are at Q1 2012 prices and are based on construction in City of London.

The key costs for Building 2 expressed as a cost per m² GIFA are shown below.

As shown, the cellular steel composite option has both a lower frame and floor cost and lower total building cost than the post tensioned concrete band beam option. On a total building basis, the steel option benefits from lower substructure costs due to the lighter frame weight and a lower roof cost due to the cost of the steel deck compared with the post tensioned slab.

The steel option has a lower floor-to-floor height (4.18m compared with 4.375m) which results in about a 5% lower external envelope cost due to the smaller area of cladding and also has lower preliminaries costs due to its shorter programme, which contributes to its lowest overall cost.

Overall, the frame and floor cost of the steel option is over 8% lower than the concrete option and over 3% lower on a whole building basis.

FIGURE 2: COSTS FOR BUILDING 2 BASED ON GROSS INTERNAL FLOOR AREA (GIFA)

	Steel Cellular Composite	Post Tensioned Concrete Band Beam and Slab
Substructure	£56/m² GIFA	£60/m² GIFA
Frame and Upper Floors	£194/m² GIFA	£210/m² GIFA
Total Building	£1,861/m² GIFA	£1,922/m² GIFA

09 | Building 2 – Programme comparison

Mace also undertook the programming analysis for Building 2, analysing both the frame and the whole building construction durations (see Figures 3 and 4).

The substructure works commence with the CFA piling, followed by excavation for the pile caps and lift pits. For the steel option, the structural frame is erected on a floor by floor basis with the steel decking installation, stud welding and concrete floor toppings following on progressively.

For the concrete option, the columns and walls progress as soon as the ground floor slab is cast, and each floor slab is constructed in two pours, with the concrete shear walls completed progressively with each floor.

The durations for construction of the ground floor slab (four weeks three days), external facade (16 weeks) and internal works to a CAT A finish (21 weeks per floor) were assumed to be the same for each option. The internal fit out is assumed to commence on the ground floor and progress up the building with a lag of two weeks between the commencement of the next floor, giving an overall duration of 39 weeks for each option.

While the substructure and ground slab construction have the same programme period (20 weeks) for each option, the steel frame has a significantly shorter frame and floor construction period (16 weeks compared with 28 weeks for the concrete option), which enables the internal fit out works to start earlier.

This results in the cellular steel option providing a significantly shorter period of both frame construction and overall programme for Building 2 compared with the post tensioned concrete option, with a saving of 12 weeks demonstrated for the frame and eight weeks across the overall programme.

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10 | Building 2 – Logistics and buildability

The assumed logistics for both the cellular steel and post tensioned concrete options are similar, with the substructure works progressing from the main core pile caps working out in two directions for both options.

Both frames would also utilise a luffing jib tower crane (about 50m radius) situated outside of the building footprint, used for distribution of the steel frame and floor decking for the steel option and for reinforcement and formwork distribution for the concrete option.

The luffing jib also helps to overcome oversailing issues common in city centres.

The superstructure works for the concrete option were assumed to progress in two phases with two or three pours required for the floor slabs.

Pumps would be used for the placing of the floor slab concrete for the post tensioned option and for the lightweight concrete topping for the steel option and both options utilise an external hoist for fit out material vertical distribution.

FIGURE 3: BUILDING 2 – CELLULAR STEEL COMPOSITE FRAME PROGRAMME

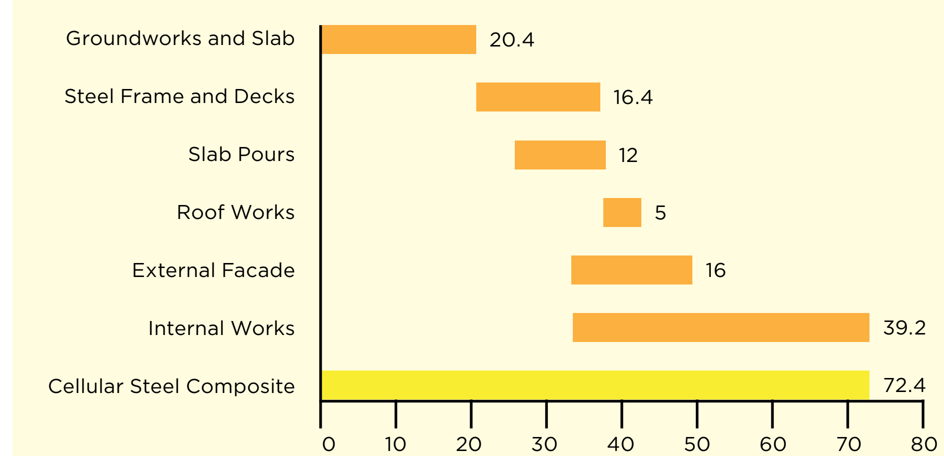
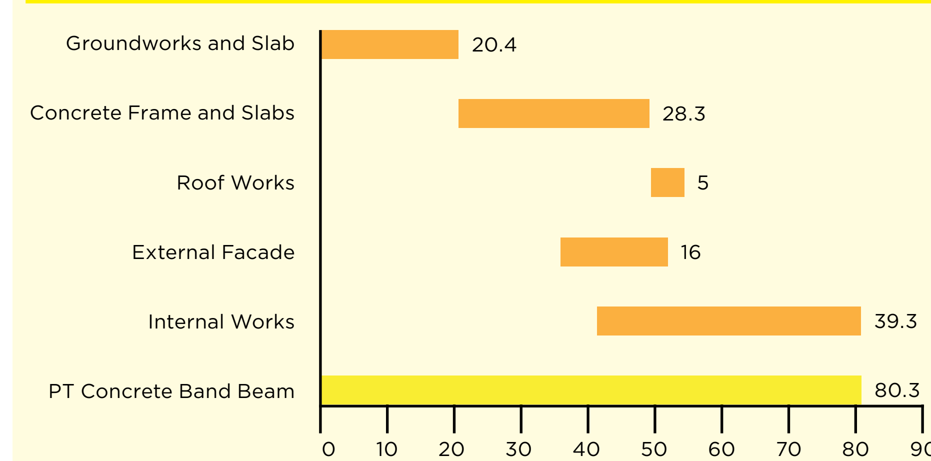


FIGURE 4: BUILDING 2 – POST TENSIONED BAND BEAM FRAME PROGRAMME



11 | Building 2 – Embodied carbon comparison

While cost and programme are key criteria in assessing design options for many projects, the comparative environmental credentials are also important. PBA therefore carried out an embodied carbon assessment for both frame options for Building 2.

Embodied carbon is considered to be the 'cradle to grave' carbon dioxide (CO_2) emissions occurring over the whole life cycle of the building, including end of life considerations but excluding the operational carbon occurring during the building use.

The study adopts a similar approach to the cost study by considering the whole building rather than just the structural frame for each option; however it focuses on the emissions from the structural elements as they represent the main differences in terms of carbon between the options.

To ensure a balanced approach, readily available industry data on materials' emissions from Target Zero publications for steel and from Concrete Centre publications for concrete have been adopted. Non-structural embodied carbon emissions have been based on benchmark information and are consistent across both frame options.

Transport emissions are based on the Department for Transport statistics for the average length of haul per commodity and on Concrete Centre data on the average delivery distance of ready-mixed concrete to construction sites.

In assessing the emissions from the construction and demolition activities on site, UK Environment Agency data, the Mace construction programming information and an estimated period for demolition have been considered.

In considering cradle to grave emissions for each option, end of life scenarios have been selected to reflect current practice, where 99% of the structural steel and 82% of the concrete reinforcement are recycled and 100% of the concrete is down-cycled to provide granular fill material.

The results of the study are shown in Figure 5 overleaf.

PBA firstly assessed the buildings in line with the cost study and using only Portland Cement for the concrete mix, which demonstrated that the embodied carbon was significantly lower for the steel frame than that for the concrete frame; with the steel option having over 23% less embodied carbon than the concrete option.

However, reflecting the common practice of using cement replacement to reduce sustainability impacts, the embodied carbon was also assessed using 30% cement replacement with fly ash and ground granulated blast furnace slag. This level of cement replacement is considered to be a reasonable replacement without having a significantly adverse impact on construction programme due to increased curing time.

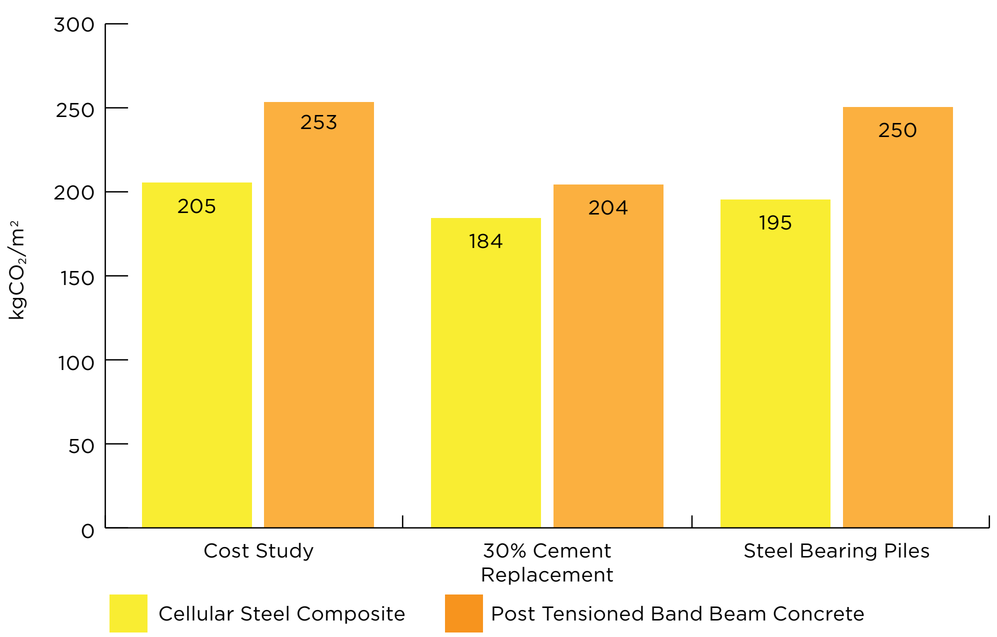
In this case, the embodied carbon reduced to 184kgCO_2/m² for the steel option and to 204kgCO_2/m² for the post tensioned concrete option. Though the difference between the steel and concrete options was reduced, it was still significant with the steel frame having around 11% less embodied carbon than the post tensioned concrete frame.

Finally, the impact of using steel bearing piles on the embodied carbon for both frame options was also assessed based on alternative substructure solutions developed by PBA and Tata Steel which utilised 356 x 368 x 152 UKBP in lieu of CFA piles.

The use of steel bearing piles results in an increased number and length of piles for both frame options, from 147nr (2,490m) to 190nr (3,984m) for the steel frame and from 150nr (3,225m) to 241nr (5,400m) for the concrete option; however, there are offsets in terms of a significant reduction in the size of pile caps and associated reductions to excavation and disposal for both options. The steel bearing piles can also be extracted at end of life and recycled or re-used elsewhere.

While the use of steel bearing piles does have a cost implication, with the substructure costs for the steel option increasing from £56/m² to £71/m² and from £60/m² to £90/m² GIFA for the concrete option, some of this will be offset through programme benefits and they can also deliver embodied carbon benefits. On a substructure only basis, the embodied carbon reduces by 15% for the steel framed option and by 5% for the concrete option and across the whole building, the embodied carbon reduces to 195kgCO_2/m² for the steel option and to 250kg/CO_2/m² for the post tensioned concrete option in the base case scenario. This demonstrates that where sustainability is a key driver, significant benefits could be realised by the consideration of a steel bearing pile substructure solution.

FIGURE 5: BUILDING 2 CRADLE TO GRAVE EMBODIED CARBON COMPARISON



12 | Summary and conclusion

The study illustrates that for both typical office building types, on a like for like basis steel framed solutions are highly competitive, with the frame and upper floor costs for the steel framed options being potentially up to 9% lower than for concrete.

The study has also highlighted the importance of considering total building cost not just structural frame cost, as the choice of the structural frame material and configuration will have associated impacts on many other elements, including the substructure, roof and external cladding. The total building cost for the steel options are on average around 5% lower than the concrete options as a result of the frame and upper floor costs noted above and smaller foundations, lightweight roofs, lower storey heights reducing cladding costs and reduced preliminaries costs.

Furthermore, the construction durations of the steel framed solutions are also shorter than the concrete framed buildings (up to 13% for Building 1 and 11% for Building 2).

The study also considers embodied carbon, which is projected to become an increasingly important criterion for design options moving forward. The study shows that in this area as well, steel framed solutions have a noticeably reduced embodied carbon compared with the concrete solutions, with an 18-30% lower embodied carbon total for the cellular steel option than the post tensioned band beam option for Building 2.

Over three key assessment criteria, the study has illustrated that steel framed solutions in current construction practice can outperform concrete options and provide lower cost, shorter programmes and lower embodied carbon. More detail on the study can be found at www.steelconstruction.org

13 |Cost update

The results of the comparison study are reflected in the latest structural steelwork cost table ranges in Figure 6.

The cost range for the low rise, short span building (Building 1) has remained constant across Q1 2012, which reflects the continuing difficult market conditions throughout the construction industry generally.

Following the production of typical designs for the two building types, the description and rate range for the high rise, long span frame noted in the table has been updated to align with Building 2. However, it should be noted that for high rise or long span structures with more complex elements or an irregular grid the rate range would need to be adjusted accordingly, and could be 15-20% higher than those noted for Building 2. To address this, a further frame type has been included within Figure 6.

Similarly, the ranges for floor costs and fire protection have been adjusted to align with the results of the cost study and market testing, with the floor costs for both the metal deck and precast options reducing by around 15%.

The continual forecasts of difficult economic conditions across 2012 continues to suggest that structural steelwork tender returns will remain stable well into 2012, and the rates in Figure 6 can be considered suitable for the cost planning of projects where the structural works will commence in Q2 and Q3 2012.

To use the table a) identify which frame type most closely relates to the project under consideration b) select and add the floor type under consideration c) add fire protection if required.

As highlighted in previous Steel Insights, before using such 'standard ranges' it is important to confirm the anticipated frame weight and variables such as the floor-to-floor heights with the design team to determine whether they are above or below the average and to adjust the rate used accordingly.

Similarly, all of the other key cost drivers of complexity, site conditions, location, function, logistics, programme and procurement strategy should be considered in turn.

FIGURE 6: INDICATIVE COST RANGES BASED ON GROSS INTERNAL FLOOR AREA

TYPE	GIFA Rate (£) BCIS Index 100	GIFA Rate (£) City of London
Frame - low rise, short spans, repetitive grid / sections, easy access (Building 1)	75 - 100/m²	90 - 120/m²
Frame - high rise, long spans, easy access, repetitive grid (Building 2)	125 - 150/m²	140 - 170/m²
Frame - high rise, long spans, complex access, irregular grid, complex elements	145 - 170/m²	165 - 190/m²
Floor - metal decking and lightweight concrete topping	40 - 58/m²	45 - 65/m²
Floor – precast concrete composite floor and topping	45 - 60/m²	50 - 70/m²
Fire protection (60 min resistance)	7 - 14/m²	8 - 16/m²
Portal frames – low eaves (6-8m)	45 - 65/m²	55 - 75/m²
Portal frames – high eaves (10-13m)	55 - 75/m²	65 - 90/m²

FIGURE 7: BCIS LOCATION FACTORS, AS AT 23 MARCH 2012

Location	BCIS Index	Location	BCIS Index
City of London	114	Leeds	100
Nottingham	97	Newcastle	94
Birmingham	99	Glasgow	102
Manchester	94	Belfast	61
Liverpool	90	Cardiff	94

THE STEEL INSIGHT SERIES

This article was produced by Rachel Oldham (associate) and Alastair Wolstenholme (partner) of Gardiner & Theobald. It is the third in a series that provides guidance on the realistic costing of structural steelwork. The next Steel Insight will appear on 27 July 2012. If you are considering using structural steelwork for your building, bridge or structure, we recommend an early dialogue with a specialist steelwork contractor. They can offer a range of support and advice, including budget estimates and value engineering. Steelwork contractors can be sourced according to project size and technical competency. This searchable function is available at

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