STRUCTURAL STEEL
CASE STUDY: P425

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Moorgate Exchange, London, UK

Figure 1 General view of the Moorgate Exchange
Courtesy: HKR Architects

Summary

Moorgate Exchange is a 12 storey office building located in the Square Mile of the City of London, which was completed in 2014. It is a landmark structure with two storey-high V-shaped columns and an angled façade which forms a roof line with stepped landscaped terraces over six levels (Figure 1). The distinct wedge-shaped form was the result of site constraints: the ‘rights to light’ of local residents, the height limitations of the St Paul’s viewing corridor and the partial overlap of the site’s footprint with the Crossrail tunnel.

The use of structural steel enabled the net lettable space to be maximised by the use of long clear spans, fire protection on the columns was minimised by infilling with concrete and a reduced overall floor depth allowed the incorporation of an additional storey. The total steel tonnage was 2,900 tonnes.

The building achieved a BREEAM “Excellent” and a LEED “Platinum” sustainability rating for its low impact on the environment through the use of high performance facades, high efficiency HVAC systems and other conservation measures. It is one of very few buildings in London to achieve these highest environmental standards.

The cost of the building was £56 Million.

Material selection

Steel was chosen for the framing material because the construction time was shorter than if the frame was made of reinforced concrete. As a steel frame weighs less, a raft foundation could be used, which is faster and cheaper to construct than a piled foundation typically needed for a heavier concrete frame. A steel framed long span structure is also far more adaptable to future tenant changes than a concrete equivalent. Table 1 summarises the economic benefits of steel construction in office buildings.

The steel columns, supplied by Tata Steel, were hot finished circular hollow sections (CHS) made from grade S355J2H in accordance with European product standard EN 10210, which stipulates a minimum yield strength of 355 MPa and a minimum toughness of 27 J at -20ºC. This steel itself was micro-alloyed with 0.030% niobium by weight which enabled the strength and toughness requirements to be easily achieved. Furthermore, the use of niobium microalloying permitted a lower carbon content to be used which significantly improved the weldability and the finer-grains developed also enhanced its formability.

Factor	Improvement	Economic benefit
Speed of construction	20 to 30% reduction in construction time relative to site-intensive construction, depending on the scale of the project.	The economic benefit depends on the business operation. In terms of overall building cost, a saving of 1% in interest charges, and 2% in early rental or use of the space is predicted.
Site management costs	Site management costs are reduced because of the shorter construction period, and the packaged nature of the construction process.	Site management costs can be reduced by 20 to 30% which can lead to a 3 to 4% saving in terms of overall building cost.
Service integration	The integration of services in the structural zone leads to reduction of 100 to 300 mm in floor to floor zone and hence to savings in cladding cost.	A 5% reduction in floor to floor height can lead to one additional floor in 20, and to a similar reduction in cladding cost, which is equivalent to about 1% in total building cost.
Foundations	Steel construction is less than half the weight of an equivalent concrete structure, which is equivalent to a 30% reduction in overall foundation loads.	Foundation costs depend on the sub-structure and factors such as underground services and represent up to 5% of the building cost. A 30% reduction in foundation loads can lead to a significant overall saving in terms of construction cost.
Column free space	Long span steel construction provides more flexible use of space, which depends on the function of the building and its future uses.	A large column in the middle of the space leads to a loss of space of approximately $1m^2$, which represents about 1% of the floor area, and may lead to an equivalent loss of rental income.

Table 1 Summary of the economic benefits of steel construction in office buildings
Courtesy: www.steelconstruction.info

Design

Figure 2 Central atrium and steel framing
Courtesy: BCSA

The 20,000 m^2 steel frame building is arranged with two main cores to provide lateral stability and a central atrium which draws natural light into the adjacent office accommodation (Figure 2). Open space, long column-free areas were a priority, which led to a 15.5 m by 7.5 m structural grid. The design ensures flexibility, as all of the floors can be subdivided if necessary.

The steel frame was designed with ease of fabrication in mind, for example standard plate thicknesses were used wherever possible to fabricate a number of different beams.

In order to maximise the available space and achieve the required 90 minutes fire performance, the internal and perimeter columns are concrete-filled circular hollow steel sections, designed according to Eurocode 4 (EN 1994). The composite columns used around the perimeter of the building had a diameter of 457 mm (12.5 mm and 16 mm thickness). If a steel-only solution had been chosen, the diameter would have been 610 mm. The internal columns had a diameter of 508 mm and thickness of 16 mm and 20 mm.

The beams were cellular I-beams, generally of 550 mm depth, to allow integration of the services within the structural zone and hence increase floor-to-ceiling heights. This enabled an additional floor to be added to the top of the building, whilst abiding with the height restrictions. This floor system is used on all the floors, with shallower but heavier beams underneath the roof gardens, to allow for waterproofing and drainage.

To achieve an acceptable dynamic performance of the long span floor system, secondary or stiffener beams at midspan were inserted between the main beams, which increased the stiffness of the floor without adding much more mass and successfully reduced the response factor.

The load was transmitted via a transfer beam structure at the second floor to two rows of four pairs of V shaped columns (Figure 3). The raked columns were formed from plated box sections and encased in concrete. The plated box sections taper from 900 mm to 600 mm in width along the member from the base upwards and weigh 11 tonnes each. They are bolted to the underside of the second floor beam at the top and to a prefabricated node at the bottom. The two columns form a 90º 2-way node at the bottom, which is encased in the concrete base (Figure 4). The nodes themselves weigh 3 tonnes. The columns feature a 1.5 m step back of the steel frame on the two long elevations on the second floor. The first floor is suspended by a series of hangers from the second floor, offering a ground floor free of columns.

The members which were externally exposed were galvanised to ensure sufficient durability to achieve a 50 year design life for the building.

Figure 3 V-shaped columns framing between ground and second floor
Courtesy: Tata Steel

Figure 4 V-shaped columns connection to a 3 tonne node at ground level, prior to concrete encasement
Courtesy: BCSA

Concrete filled CHS columns with reinforcing bar cages were utilised to provide 90 minutes fire protection without the need for any external fire protection on all of the internal and perimeter columns. Tata Steel's Firesoft design software was used for this analysis. This, coupled with a structural fire engineering analysis on the floor plates, allowed intumescent paint to be removed from a significant proportion of the steelwork.

The main I section beam to CHS column connections were generally fin plates slotted through the CHS column walls and were assumed to be nominally pinned. Under ambient loads, joint resistance satisfied the requirements of Eurocode 3 and Eurocode 4. I-section stubs with webs slotted through the column walls were also used. The principles of 'simple construction' were adopted for the beam to column connections in which the joints are assumed nominally pinned (a widely used assumption in the design of multi-storey braced frames in the UK).

The CHS columns were fire protected locally around the connection zones with intumescent paint to achieve the required 90 minutes fire resistance (Figure 5).

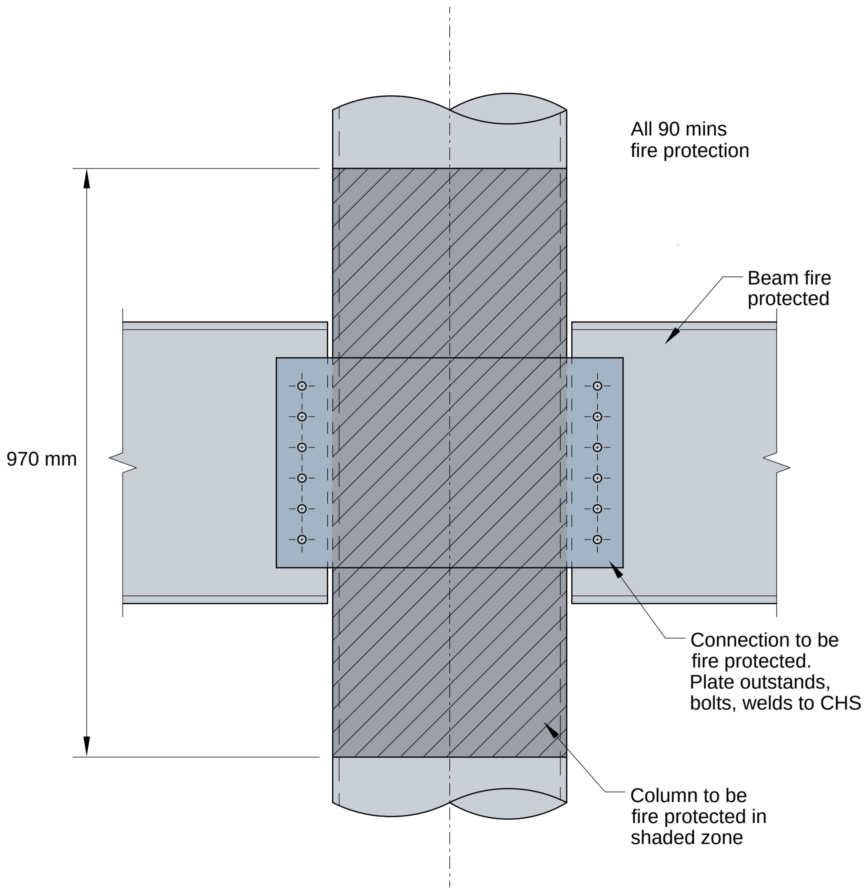

Figure 5 Fire protection on CHS column at a typical I beam connection

Fabrication and erection

The steel frame was erected in 20 weeks, just after the slip formed cores were constructed. Provision for a tower crane through the floor plates was included in the base floor design. Stubs welded to the sections enabled fast and efficient connections to be achieved. The installation of the raking columns required propping during the erection process, until fabrication of the connections at the top and bottom of the column was completed. Coordination of the construction of the steel frame with the cladding interfaces was a complex task because strict glazing tolerances had to be met.

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Parties involved

Architect	HKR Architects
Client monitoring architect	Pringle Brandon Perkins+Will
Structural Engineer	Ramboll
Project manager	GVA Second London Wall
Steelwork Contractor and design of CHS columns and steel connections	Severfield (UK) Ltd
Main Contractor	Skanska UK Ltd
Client	Blackrock / Telex Sàrl

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Cover image: Moorgate Exchange by night, courtesy of Tata Steel.