OFFSITE MODULAR STEELWORK:
ADVICE TO CLIENTS

SCI Steel Knowledge

BCSA

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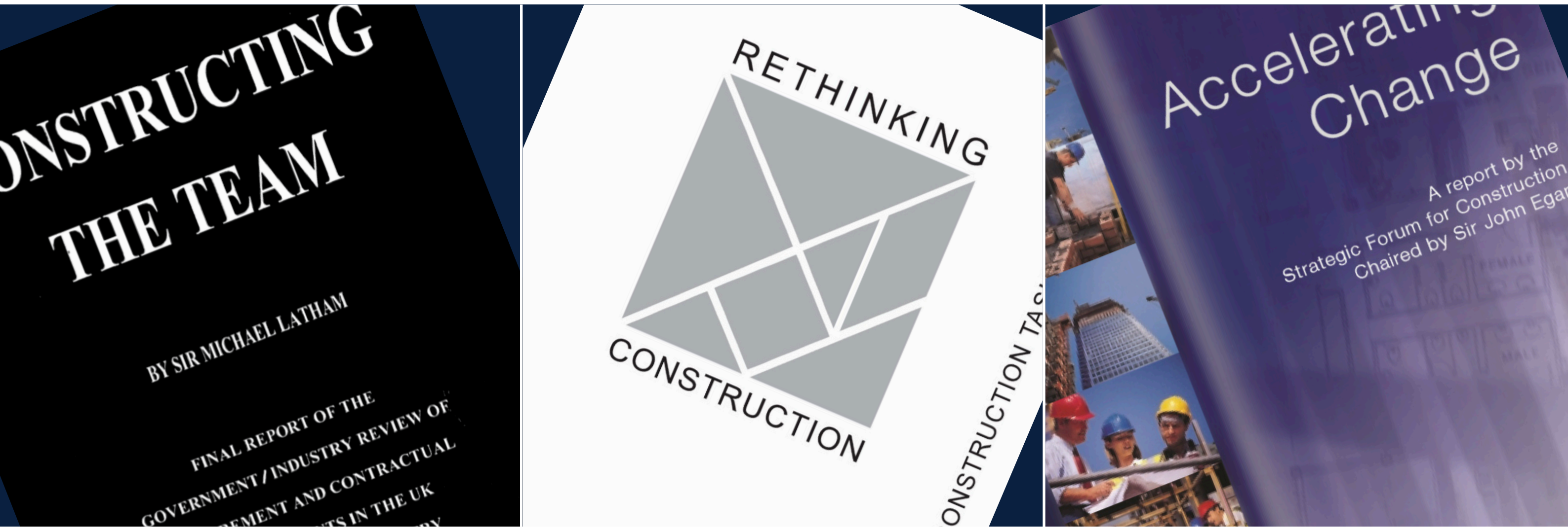
1. OPPORTUNITIES FOR CONSTRUCTION CLIENTS

Compared to typical 2020 programmes and costs, multi-storey steel buildings can be constructed in shorter periods and at reduced cost. Steel composite cores, discussed in Section 2.1, are claimed to have shortened a construction programme from 18 months to 10 months, and reduced costs by 2%.

Construction clients are in a position to insist their professional advisors and construction partners collaborate in such a way to deliver overall better value than is commonly the case. This is not a new message; successive renowned studies since 1994 have reached the same conclusion.

The advantages presented in this document are associated with the use of structural steelwork, which is already a lightweight, offsite fabrication, relatively fast form of construction. However, further benefits can be obtained by moving even more of the construction process offsite and increased prefabrication.

Structural solutions which deliver higher quality, faster construction and reduced safety risks are presented in a companion document[1]. The proposed solutions are evolution not revolution; no technical risk is involved. Technical solutions may be classed as standardised, meaning that repeatable components are manufactured offsite. Some solutions have already been successfully used in landmark projects, demonstrating the benefits that arise. The key characteristic is to move more construction effort to the offsite factory, rather than the construction site.



1.1 FASTER, HIGHER QUALITY CONSTRUCTION

Moving activities offsite shortens the construction period onsite. This may be the key advantage of an integrated modular solution.

A largely offsite construction process has the key advantages of:

- Shorter site construction periods;
- Enhanced quality, due to factory control;
- Reduced deliveries to site;
- Reduced manpower on site;
- Positive impact on safety;
- Earlier dry envelope, and early access for the following trades;
- Reduced “wet” trades (such as concrete casting);
- Reduced interfaces between components.

The capital cost of some offsite technologies may be higher than the equivalent ‘traditional’ construction methods – advantage is derived from an earlier return on investment when considering a project holistically, together with the value of the benefits listed above.

1.2 CONCLUSIONS FROM OTHER STUDIES

Improvement in construction efficiency has been an objective of the UK Government for many years. Consistently, studies of construction efficiency highlight the role of the client, and the opportunities arising from collaborative working amongst the construction partners. Relevant conclusions relating to offsite manufacture are presented below.

CONSTRUCTING THE TEAM (LATHAM, 1994)

- Collaborative working practices could achieve a 30% cost saving
- The contributions of … M&E contractors and consultants to the construction industry is immense. The more complex the building, the higher is the likely value of the M&E input and the greater the design responsibility which will be passed by the architect/engineer to the building services consultant and the specialist contractor.

RETHINKING CONSTRUCTION (EGAN, 1997)

- We have identified five key drivers of change which need to set the agenda for the construction industry at large: committed leadership, a focus on the customer, integrated processes and teams, a quality driven agenda and commitment to people.

ACCELERATING CHANGE (2002)

- Clients should require the use of integrated teams and long term supply chains and actively participate in their creation.
- Product manufacturers, suppliers and specialists can develop solutions that involve less site processing, increased standardisation, pre-assembly and prefabrication, which takes work off site, reduces health and safety risks and improves quality and reliability. They can also advise on availability of new products and innovative solutions, which, when linked closely to design and installation, can bring real benefits.

1.3 GOVERNMENT INITIATIVES

Recent Government initiatives have emphasised the advantages that flow from increased offsite manufacture. In 2017 as a manifestation of Government commitment, the Chancellor of the Exchequer announced that five central government departments would adopt a presumption in favour of offsite construction, leveraging their buying power to support the modernisation of the construction sector.

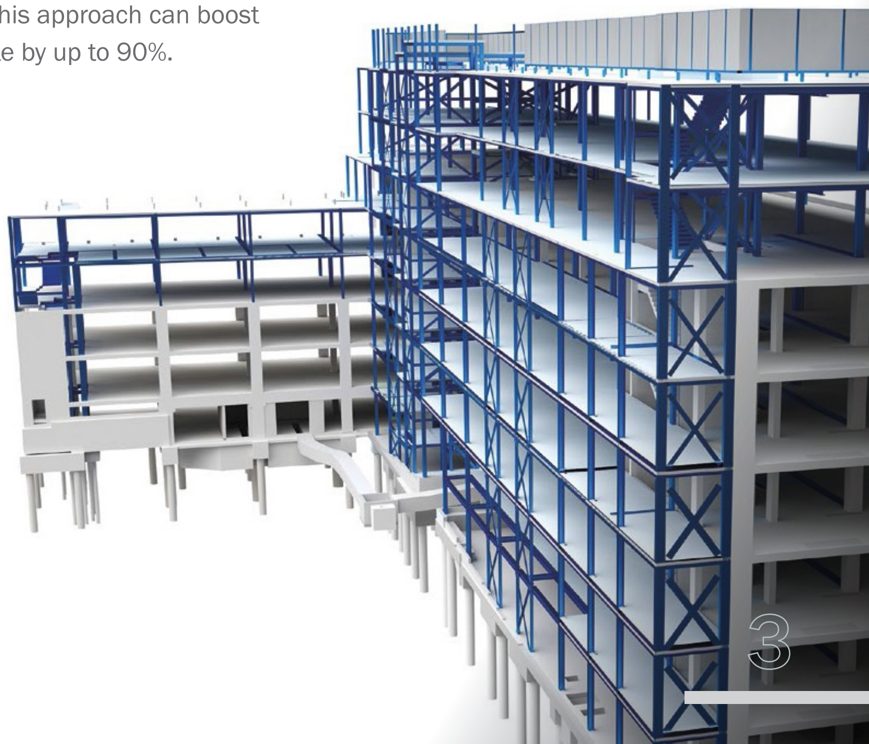
Subsequently, the government set out a 'new approach' to building, to be adopted across all government departments where it presents value for money. This is described as a platform approach to design for manufacture and assembly (P-DfMA).

A platform approach is the use a set of digitally designed components across multiple types of built asset that are then used wherever possible, minimising the need to design bespoke components for different types of asset.

By taking a consistent approach and using standardised and interoperable components across a range of different buildings, the government hopes to encourage the creation of a new market for manufacturing in construction and to take advantage of economies and efficiencies of scale.

The Treasury believes that adopting this approach can boost productivity whilst also reducing waste by up to 90%.

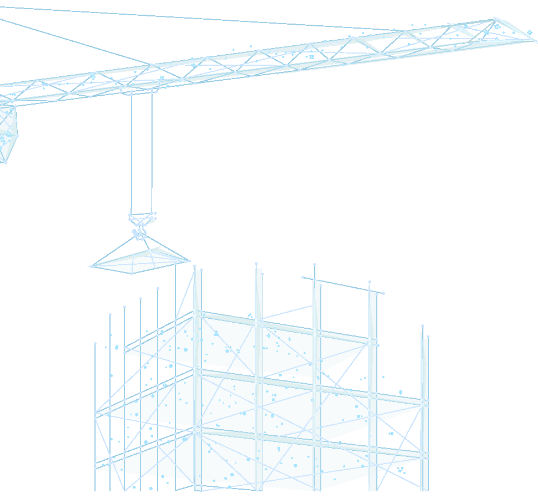
Technical solutions for multi-storey structures which meet the objectives of P-DfMA and deliver benefits to the client are described in Section 2.



2. STRUCTURAL SOLUTIONS

This section describes technical concepts for multi-storey buildings which should be considered when developing a scheme design. A companion guide[1], aimed at structural designers, develops these solutions in greater depth. All the concepts presented are already used (as presented or with minor variations) for some applications. This means they offer the possibility for immediate benefits if applied to a broader range of buildings.

Two general multi-storey building types were considered during the development of the proposed technical concepts:



HIGH QUALITY, CITY CENTRE OFFICES

The British Council for Offices (BCO) recommends 7.5 m, 9.0 m, 12.0 m and 15.0 m column grids. Column grids for high quality offices in major urban centres would typically adopt the longer spans within in this range between 9 m × 12 m and 9 m × 15 m.

Common structural forms for this type of multi-storey building involve a slip-formed concrete core, completed in advance of the floors. Floors are usually composite steel-concrete slabs supported on composite beams, often with perforated webs to facilitate the passage of services. Composite floors are very structurally efficient, but involve a number of site operations and wet trades.

RESIDENTIAL

Typical grids for residential buildings typically range from 6.0 m to 7.5 m for perimeter columns and up to 9 m for internal columns.

The shorter spans in residential construction mean that in-situ concrete is a common solution. Light gauge modular construction (involving three dimensional completed units, generally based around a frame constructed from thin, galvanised steel members) is also popular for this form of building. Taller residential structures are likely to be stabilised by a slip-formed or jump-formed concrete core.

2.1 FASTER, PRECISE STRUCTURAL CORES

Recent experience in North America has shown twin skin steel composite cores to have thinner walls and to be substantially quicker than the concrete equivalent[2]. Thinner walls also increase the useable floor area and reduce the load on the foundations.

Although a steel core may be more expensive than the concrete equivalent, the construction of Rainier Square, Seattle, with a twin skin steel core was completed in 10 months rather than the 18 months anticipated with a traditional concrete core and at reduced cost overall[3].

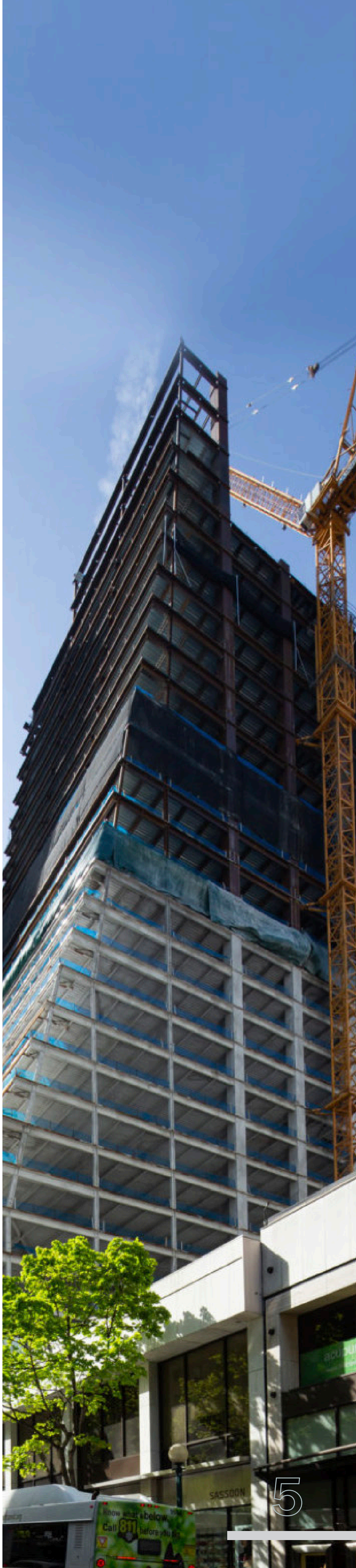
In this approach, prefabricated panels comprising external steel plates and internal shear studs are erected in the 'empty' condition to form the core. The concrete infill to the panels is placed at a later date and is not on the critical path.

Amongst the advantages cited for this form of construction is the relative ease of making connections between the floor steelwork and the steel core. Straightforward connection details may be fabricated as part of the steel core, and the usual incompatibility between the tolerances of a cast concrete core and the precision of the fabricated steelwork is overcome.

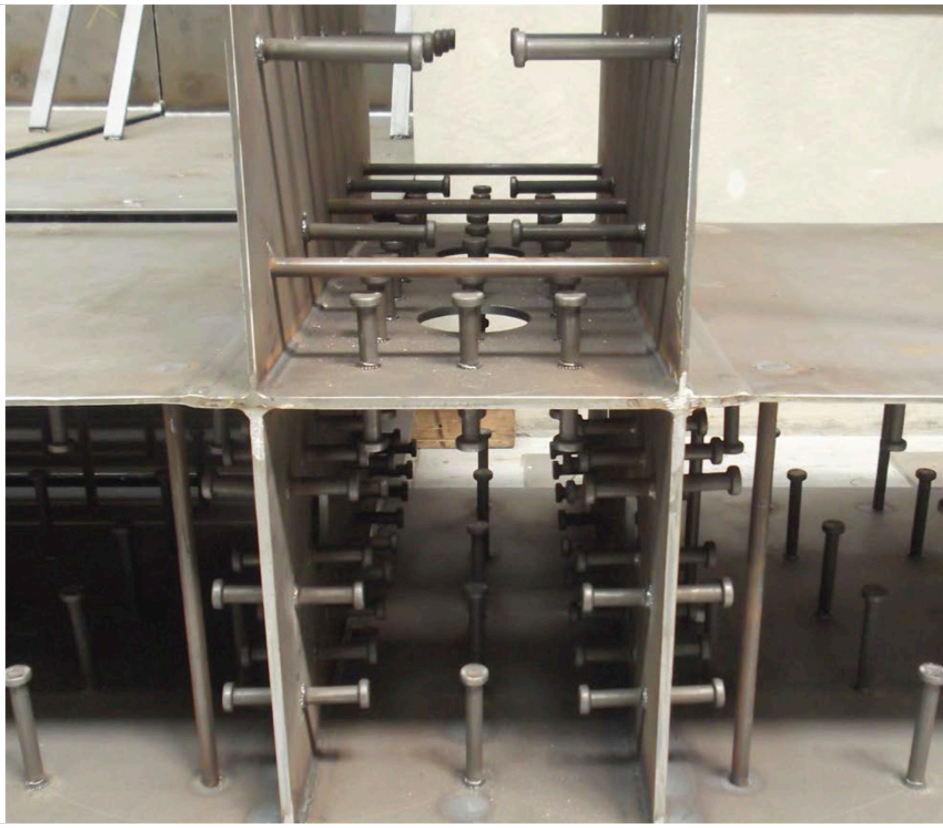
Although this technology is presented as 'radical' in North America[2], where it is described as 'Speedcore', the concept of a twin skin panel has is mature and was first used in the UK around 2005. Then, the product was known as 'Corefast' and the prefabricated panels were known as 'Bi-Steel'. Contemporary case studies using 'Corefast' demonstrated cores could be constructed up to six times faster than a typical concrete core, with a 40% reduction in the thickness of the walls of the core compared to a reinforced concrete solution[4].

Bi-steel was a proprietary product fabricated by one manufacturer using unique processes. Today, the same generic product may be fabricated with orthodox techniques by any manufacturer.

In the UK, it is commonly thought that the initial cost of a steel core solution outweighs the advantages, compared to a concrete core, unless fast completion of the core is essential, or there are other constraints such as limited access for forming a concrete core.



Bi-steel panels used as Corefast core



Steel concrete composite prefabricated panel joint

There are no technical reasons to prevent the development of a twin skin steel core solution. Advice on scheme design, final analysis and connection details is available. Design guidance in accordance with the Eurocodes has been published[5].

In addition to the shorter construction programme, the use of a double skin composite core has additional benefits:

- The core walls are thinner than the plain concrete equivalent, increasing the useable floor space;
- The cores are lighter than the plain concrete equivalent, reducing the demand on the foundations;
- Tolerances are precisely controlled, and the interface between the core and the surrounding steelwork is the responsibility of one construction party;
- Supports for the surrounding steelwork and floor slabs can be pre-installed on the core panels – no cast-in plates are required;
- The panels are self-supporting and stiff – typically four storeys and the surrounding steelwork may be erected before the concrete infill to the core is placed;
- Work at height is significantly reduced.

2.2 STANDARDISED STEEL COLUMNS

In typical multi-storey construction, columns are two or three storeys in height and generally fire protected with an intumescent coating, applied offsite. Steel beams are connected directly to the columns.

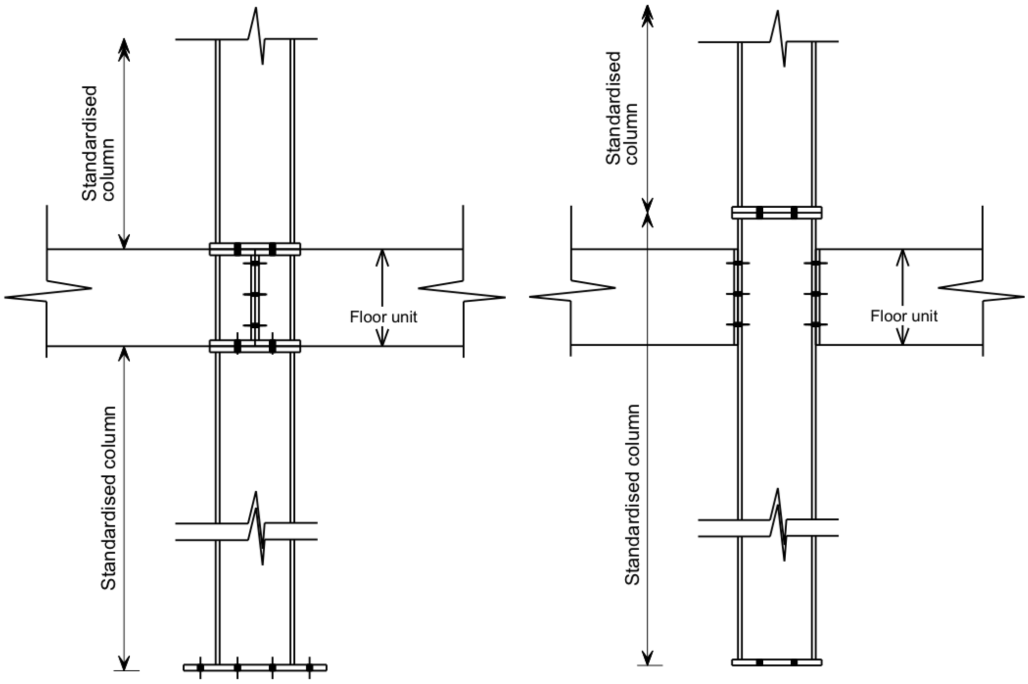
As the use of robotic material handling and welding increases in the UK, standardised, storey-height columns facilitate a P-DfMA approach, using standardised steel sections, components and offsite assembly.

The use of single storey columns is particularly appropriate in combination with the 'dry floor' solutions described in Section 2.3.

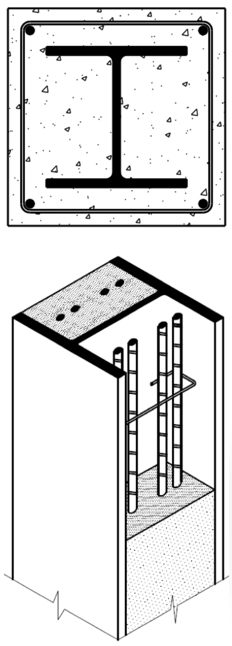
Conceptually, the single storey columns are 'plain', with simple end connections, to facilitate mass production offsite. At floor levels, intermediate sections could be fabricated to accept the floor panels, or the necessary column continuity could be provided within the floor units themselves.

The same performance can be achieved with less material by producing composite column sections, manufactured offsite. Composite columns are steel sections partially or fully encased in concrete, or hollow steel sections filled with concrete, both options being facilitated by offsite manufacture.

For very high loads, the columns are likely to be Universal Columns (UC), which have concrete cast within the section profile. Alternatively, hollow sections, typically circular or square profiles, may be filled with concrete.



Alternative column arrangements



Using concrete compositely with the steel section increases the resistance in both normal conditions and in fire conditions. Composite columns can provide typical fire resistance periods of up to 90 minutes for the otherwise unprotected steelwork[6].

Alternative column arrangements

2.3 DRY FLOOR PLATES

Floors in multi-storey buildings are typically composite slabs, comprising profiled steel sheet and concrete. The supporting beams are generally composite, with shear studs welded through the steel sheet to the top of the steel beam.

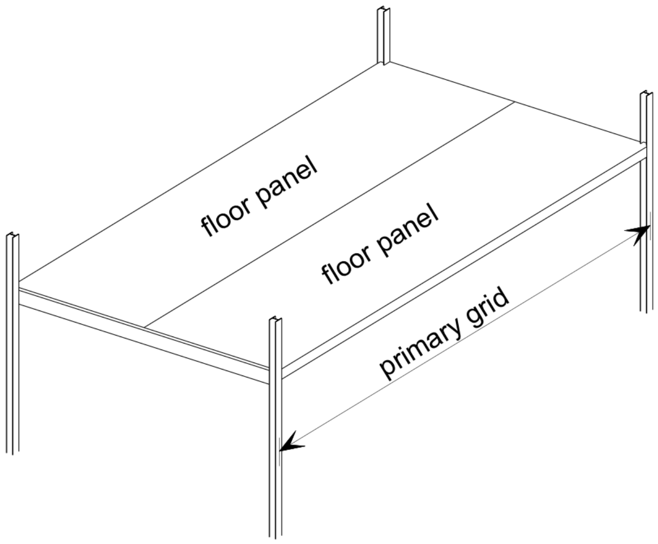
This floor solution involves laying out and fixing the decking sheets, adding edge trim, completing the through-deck welding of shear studs, laying reinforcement and pouring the concrete.

These time-consuming operations may be avoided if complete floor panels were erected, without the need for concrete to be placed on site. Such solutions are often referred to as ‘dry’ solutions, as concrete is not required.

A number of ‘dry’ floor solutions may be considered, described below. In many cases the overall size of the panel which can be erected is limited by the transport restrictions between the factory and the site.

The offsite, factory production of the floor plate panels means that the panels are precise components. Panels are shallow, typically less than 20% of the storey height, meaning that multiple panels may be transported to site in one load, in contrast to transporting single, storey height modules.

Conceptually, panels are rectangular in shape with some form of floor construction (concrete, timber, etc) and a perimeter steel member on each side. The steel supporting members span to primary steelwork supports.



Floor panel concept

The design of a panelised solution must address a number of requirements covered in more detail in the companion technical guide[1].

The following list illustrates the technical features common to a panelised floor solution:

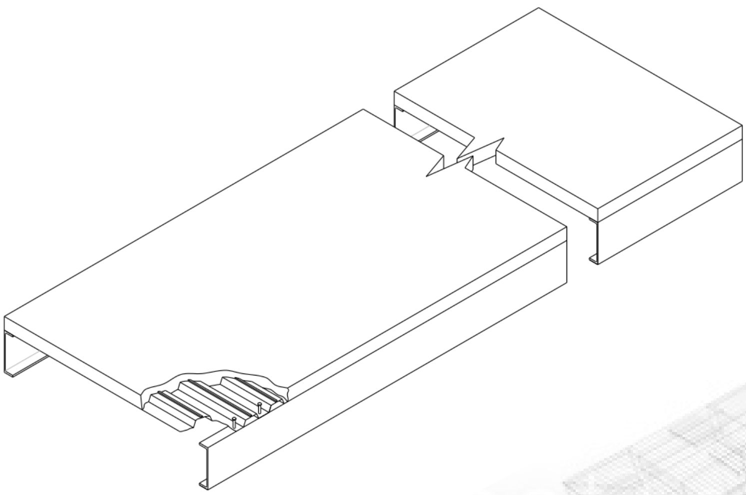
- Panel weight (for site craneage).
- Connections between panels (to form a floor diaphragm).
- Necessary sealing between adjacent panels for acoustic and fire performance.
- Dynamic performance.
- The design of the primary beams supporting the prefabricated panels. Primary beams are likely to be deeper that traditional solutions as they will generally be non-composite.
- The passage or services, which is likely to require perforations in the supporting panel members and the primary steelwork supports.

COMPOSITE FLOOR PANELS

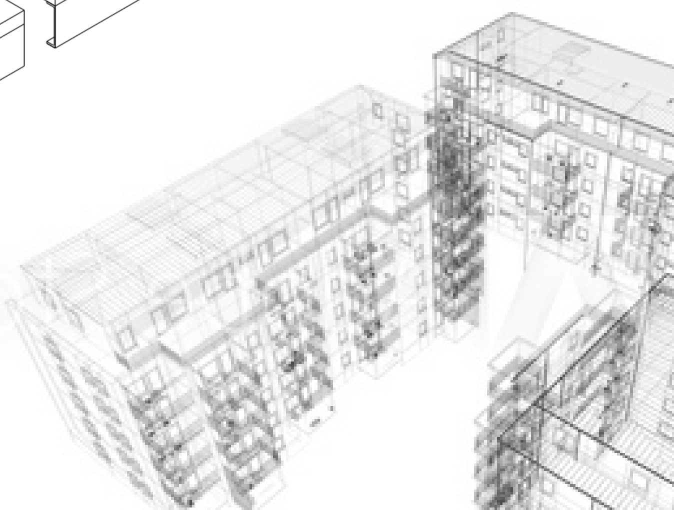
This is an orthodox solution, comprising conventional profiled steel sheet and concrete, acting compositely with the supporting steelwork, but with the normal construction activities moved offsite.

Completed panels would typically be approximately 3 m wide (to suit the minor column grid) with a length to suit the major column grid (9 m, 12 m, 15 m etc). The steelwork would be deep fabricated channels, acting compositely, or cellular beams. Several units would be used to complete the floor panel.

Alternative column arrangements



A typical 3 m × 12 m panel would weigh approximately 14 tonnes.



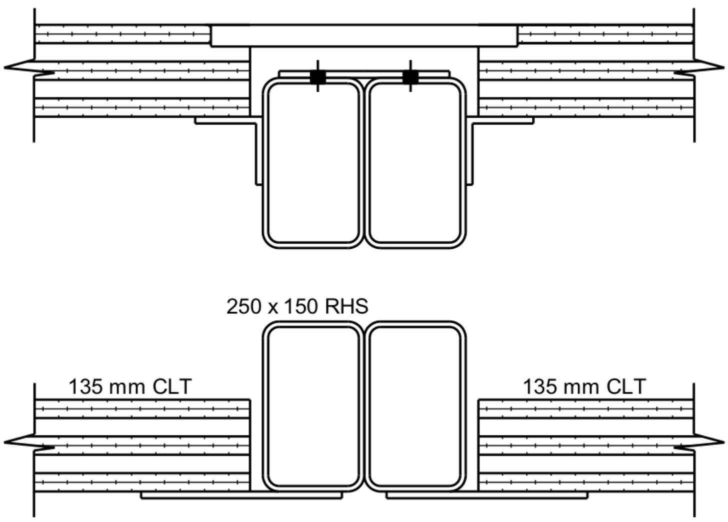
CROSS LAMINATED TIMBER (CLT) FLOOR PANELS

In this solution, the concrete slab used in composite floor panels is replaced by CLT. A CLT floor panel only 140 mm deep would be capable of spanning 3 m under residential loading, meaning that the floor construction can be very shallow. For many arrangements, the primary steel support can be hollow sections, contributing to a lightweight, shallow solution.

A thicker CLT panel would be required for typical office arrangements.

The steelwork and CLT can be arranged to provide an uninterrupted, flat upper surface, or alternative details may be used if a raised floor is envisaged.

> For a typical CLT thickness of 140 mm, protected by a single layer of 12.5 mm plasterboard and subject to an imposed action of 5 kN/m^2 a fire resistance period of 90 minutes can be achieved[7].



Alternative CLT and steel details

CLT panels can be produced with fire resistances up to 90 minutes[8].

Construction with CLT is more expensive than steel or concrete solutions, but once reduced programme times and reduction in waste is taken into account, it is suggested that the cost of a CLT solution is similar to traditional construction[9]. CLT solutions have positive environmental credentials and can be readily deconstructed. It CLT cannot be reused, it has value as biomass.

LIGHT GAUGE FLOOR CASSETTES

'Light gauge' steelwork refers to cold rolled steel sections, usually C sections, formed from galvanised steel typically 1 – 3 mm thick. A wide range of profiles is available from a variety of manufacturers.

The use of cassettes, formed with light gauge steel floor joists with a chipboard or orientated strand board (OSB) floor is a variation of existing technology commonly used in light steel modular construction. The steel joists and board(s) are combined in the factory into panels (cassettes), rather than supplied to site as individual elements. Light gauge steel joists are often used back-to-back, and can accommodate spans up to 6 m. Acoustic performance is provided by mineral wool quilt within the cassette. Fire protection is provided by layers of fire resisting boards.

For residential imposed loading, and 6 m spans, the C sections are typically 250 – 300 mm deep, 2.5 mm thick. C sections may be perforated to facilitate the passage of services.

Typical light gauge floor cassette

As the description suggests, the solution is lightweight, with a typical weight of only 1 tonne for a panel (cassette) 3 m × 6 m.

2.4 FACADE AND ROOF PANELS

Modularised external wall panels are formed with a stiff structural core, insulation and a vapour barrier on the external face. Panels may have internal finishes factory fixed, and have openings for windows provided. The primary advantage of prefabricated panels is the earlier dry envelope (allowing earlier access for following trades) and the shorter overall construction programme. A 25% reduction in overall construction programme is possible[10].

Prefabricated panels are dimensionally precise and are engineered to provide acoustic, thermal and fire performance.

LIGHT GAUGE WALL OR ROOF PANELS

Light gauge steelwork may be used to provide the structural frame of a modularised wall or roof panel. Single panels, typically around 3 m wide may cover several storeys, supported at the base and attached to intermediate floor levels. Tolerances of the floor construction are accommodated by the support details which allow for adjustment.

Insulation may be placed within the steel cassette and a weatherproof cladding attached offsite.

The advantages of this system are:

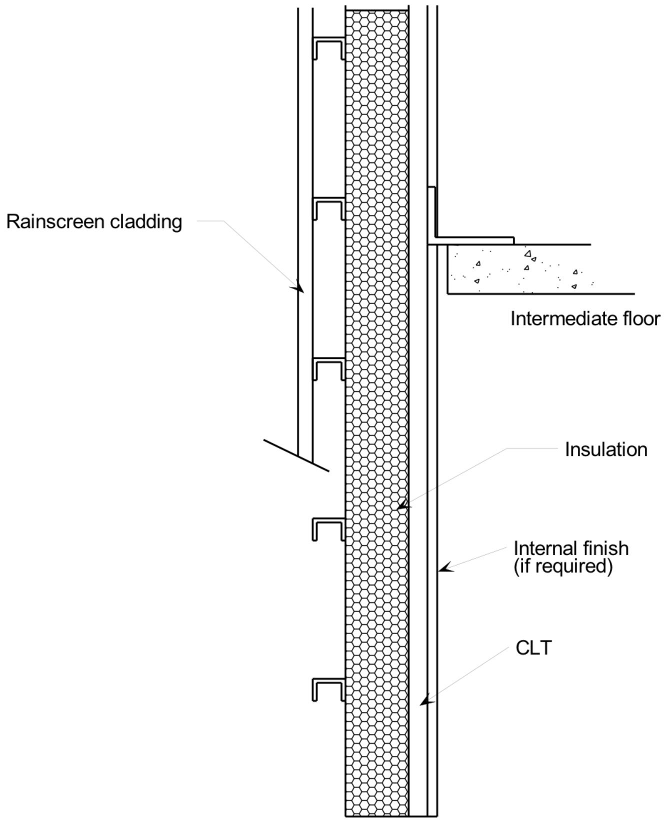
- Rapid completion of a weathertight envelope;
- Panels fabricated to precise dimensions (± 1 mm);

Steel cassettes may be used at any height in the building, unlike timber based panels which cannot be used above 18 m.

CLT WALL PANELS

As an alternative to light gauge steel, cross laminated timber (CLT) may be used to provide the structural resistance necessary for wall panels. Single CLT panels 3 m wide may cover several storeys, as panels can be manufactured up to 20 m in length.

In the same way as light gauge steel cassettes, CLT panels may have both internal and external finishes applied offsite.



Section through a CLT wall panel

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