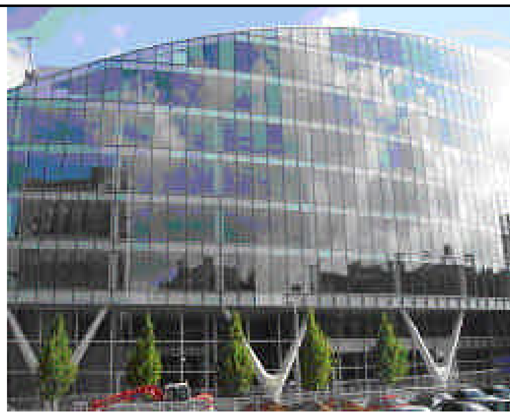
ANNEX 3-A

Best Practice
COMMERCIAL BUILDINGS
IN EUROPE

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1 INTRODUCTION

Design of commercial buildings is strongly influenced by issues such as the clear floor spans, the access and circulation space, integration of building services, and the site and access conditions. Speed of construction and minimum storage of materials on site, means a high level of prefabrication, are often of critical importance for inner city projects.

A recent cost comparison study showed that the building structure is generally only 10% of the total building cost – and the influence of the choice of structure on the foundations, services and cladding are often more significant. In reality, the building design is a synthesis of architectural, structural, services, logistics and buildability issues. Figure 1.2 shows a modern commercial building in steel in which this synthesis has been adopted. Long span steel systems with provision for service integration have dominated modern commercial building design, as illustrated in Figure 1.3, leading to an increase of market share in this sector.

Figure 1.2 *Modern commercial building in steel*

Figure 1.3 *Service integration in cellular beams*

2 GENERAL INFORMATION

2.1 Commercial building market

Typically city centre projects are relatively large (8,000 – 20,000 m^2) in floor area and 4–10 storeys in height. Most buildings are designed in composite construction with spans in excess of 12 m with a strong trend towards 15–18 m spans. Height of buildings is often controlled by planning authorities.

There is still a strong demand for high quality office space, especially in inner cities. Corporate headquarters for banks and other high profile companies require that buildings are built to high architectural and environmental standards. Investment 'value' is the main criterion for choice of the building architecture, form and servicing strategy. New buildings are typically high-rise offices, many of which are curved in form, and have highly glazed facades and atria.

Increasingly there is a trend towards 'mixed use' developments. This involves the building of commercial, retail and residential parts in a 'live-work-play' environment, where all facilities are provided in one building or project. On the other hand the recent trend to build on 'greenfield' (virgin land not previously built upon) or out of town sites, such as science and technology parks has noticeably decreased, as planning pressure to build in city centres increases.

Speed of construction is seen as the major selling point for steel, together with opportunities for service integration in long span construction. Pre-assembly of services, lifts, toilets and plant rooms is also important in major projects. Long term flexibility in use is an important issue to clients and speculative developers, whilst information technology and Building Management Systems (BMS) are important in planning and design.

2.2 Construction programme

The construction programme is a key concern in any project, and should be considered at the same time as considering the cost of structure, the services, cladding and finishes. The structural scheme has a key influence on programme and cost, and structural solutions, which can be erected safely, quickly to allow early access for the following trades.

Cranes

The number of cranes on a project will be dominated by:

- The site footprint – can cranes be physically installed with a sensible coverage of the building site, including off-loading from roads?
- The size of the project – can more than one crane be utilised?
- Commercial decisions on cost and programme benefits.

Multi-storey structures are often erected using a tower crane. For tall buildings, the increased time lifting the component into position from ground level is important. More significantly, there are usually competing demands from other trades for the use of tower cranes, which can slow overall progress for the steelwork erection. For larger projects, erection schemes that enable other trades to commence their activities as the steelwork progresses will be required. Erection rates are dominated by “hook time” – the time connected to the crane. Fewer pieces to erect, or more cranes, will reduce the erection programme.

Smaller inner-city sites are often served by a single tower crane, which is used by all trades. In these circumstances, craneage is limited, and smaller piece counts of steel components are an advantage.

Composite floors

Composite floors comprise profiled steel decking, which is lifted onto the steelwork in bundles and usually man-handled into position. Safety nets are erected immediately after the steelwork and before the decking placement. Once the decking is placed it is for safety reasons provisory fixed one to each other as well as to the steel beams. Steelwork already erected at upper levels does not prevent decking being lifted and placed, although decking is usually placed as the steelwork is erected. Completed floors may be used as a safe working platform for subsequent erection of steelwork, as shown in Figure 2.1. For this reason, the upper floor in any group of floors (usually three floor levels) is often concreted first.

Figure 2.1 *Composite floors create a safe working platform during construction*

Precast concrete planks

Placing of precast concrete planks becomes difficult if the planks must be lowered through erected steelwork. Better practice is to place the planks as the steelwork for each floor is erected, and to have the plank supply and installation as part of the Steelwork Contractor's package is often an advantage. Generally, columns and floor steelwork will be erected, with minimal steelwork at upper levels sufficient to stabilise the columns, until the planks have been positioned. Steelwork for the upper floors will then continue.

Erection rates

As an indication only, an erection rate of between 20 and 30 pieces per day is a reasonable rate. With average weights of the components, this equates to approximately 10 to 12 tonnes per day. There is therefore benefit in using fewer long span beams.

2.3 Design life

When proposing any structural scheme, it is acknowledged that the structure has a design life many times greater than other building components. For example, service installations have a design life of around 15 years, compared to a design life of 60 years for the structure. Building envelopes for typical office construction have a design life of between 30 and 60 years.

Similarly, the space usage of the interior is likely to change constantly. Schemes that allow maximum flexibility of layout are to be preferred. A structure can be designed for flexibility and adaptability, by using:

- Longer floor spans.
- Higher ceilings.
- Freedom in service distribution.

2.4 Site conditions

Ground conditions may strongly influence the column layout. Increasingly, structures are constructed on poor ground conditions, or on 'brownfield' sites (land previously built upon). In city centres, major services and underground works, such as tunnels, often dominate the chosen solution. Poor ground conditions tend to require a lightweight solution involving fewer foundations. This would necessitate longer spans for the superstructure.

A confined site can place particular constraints on the structural scheme, for example the size of the elements that can be delivered and erected. Composite flooring is often preferred because of its ease of structure and handling.

2.5 Service integration

Most large office-type structures require air conditioning or 'comfort cooling', which will necessitate both horizontal and vertical distribution systems. The provision for such systems is of critical importance for the superstructure layout, affecting the layout and type of members chosen.

The basic decision either to integrate the ductwork within the structural depth or to simply suspend the ductwork at a lower level affects the choice of member, the fire protection system, the cladding (cost and programme) and overall building height. Other systems provide conditioned air from a raised floor.

The most commonly used systems are the Variable Air Volume system (VAV) and the Fan Coil system. VAV systems are often used in buildings with single owner occupiers, because of their lower running costs. Fan Coil systems are often used in speculative buildings because of their lower capital costs.

Generally, a zone of 450 mm will permit services to be suspended below the structure. An additional 150–200 mm is usually allowed for fire protection, ceiling and lighting units and a nominal deflection (25 mm). Terminal units (Fan coil or VAV units) are located between the beams where there is more space available.

Service integration is achieved by passing services through penetrations in the supporting steelwork. These may be individual openings formed in steel beams, or multiple regular or irregular openings created in fabricated beams. Cellular beams have regular circular openings in the web, which are created by welding together two parts of a rolled section. The top and bottom steel sections may be cut from different sizes and fom different beams in even different steel grades (hybrid sections). This allows both a solution for service integration as well as an increase of resistance. Elongated openings may be created in cellular beam construction, as illustrated in Figure 2.2.

Figure 2.2 *Elongated openings with horizontal stiffeners*

If there are no overall height constraints, it is usually more efficient to accommodate services below the floor structure. The penalty is an increased construction depth of each floor, and increased cladding areas around the structure. Both the increased cost of cladding and the possible programme implications should be considered.

Service distribution below the floor in integrated floor systems is illustrated in Figure 2.3. Other innovative forms of service integration in variants of integrated floors have been developed, as in Figure 2.4. In this project, the stainless steel decking is exposed and acts to regulate internal temperatures by the thermal capacity of the floor slab. The air-conditioning and other devices as lighting systems are integrated in the design and remain visible.

Figure 2.3 *Service distribution below the floor with integrated floor beams*

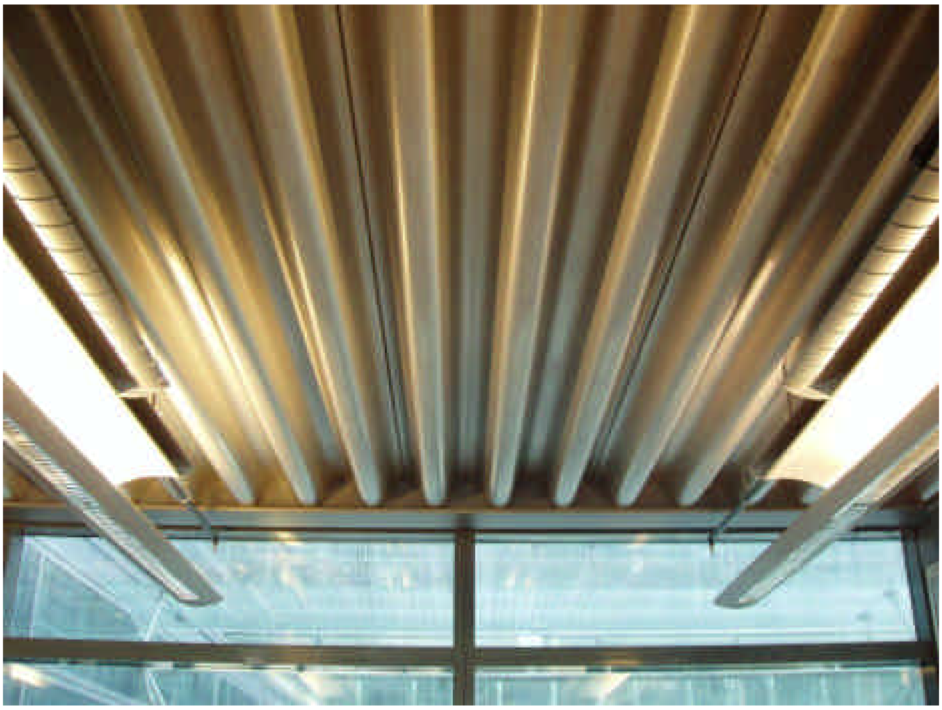


Figure 2.4 *Stainless steel composite decking used at the Luxembourg Chamber of Commerce*

2.6 Floor dynamics

Floor response is assessed first by calculating the fundamental frequency of the floor. If the fundamental frequency of the floor structure is greater than 3Hz, the floor is generally considered to be satisfactory. Whilst this was generally acceptable for busy workplaces, it is not appropriate for quieter areas of buildings where vibrations are more perceptible.

A more appropriate approach is an assessment based on a 'response factor' that takes into account the amplitude of the vibration, which is normally measured in terms of acceleration. Higher response factors indicate increasingly dynamic floors that are more noticeable to the occupants.

In practice, response factors are reduced (i.e. vibration is less noticeable) by increasing the mass participating in the motion. Long-span beams are generally less of a dynamic problem than shorter spans, which is contrary to ideas based on natural frequency alone.

Beam layout is often important, as longer continuous lines of secondary beams in composite construction result in lower response factors than shorter lengths, because more mass participates in the motion with longer lines of beams. Figure 2.5 shows two possible arrangements of beams. The response factor for arrangement (b) will be lower (less noticeable to occupants) than arrangement (a), as the participating mass is increased in arrangement (b).

Damping reduces the dynamic response of a floor and partitions increase the damping ratio by 3 to 4.5%. Floor response is decreased by partitions at right angles to the main vibrating elements (usually the secondary beams). Bare floors during construction are likely to feel more 'lively' than when occupied.

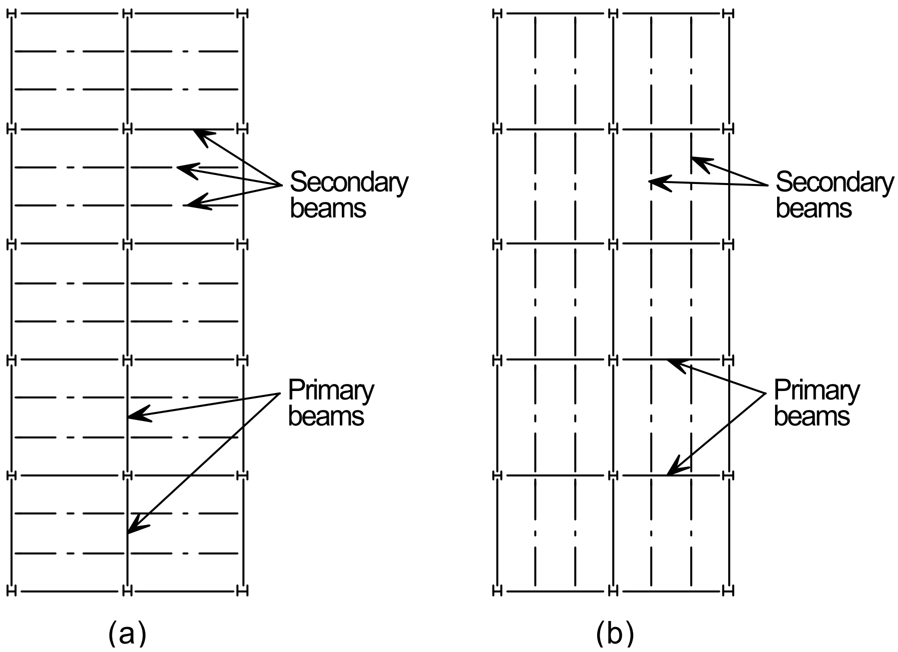


Figure 2.5 *Alternative beam layouts*

2.7 Fire safety

Building designers should consider the implications of fire resistance when arranging choosing the structural configuration and should address issues such as:

- Means of escape.
- Size of compartment.

- Access and facilities for the Fire Service.
- Limiting the spread of fire.
- Smoke control and evacuation.
- Adoption of sprinklers.

Fire resistance

In addition to the above, structural performance in the event of a fire must meet prescribed standards, expressed as a period of fire resistance of the structural components. As an alternative, a ‘fire engineering’ approach may be followed, which accounts for the fire safety of the whole building, considering the real fire, the structure use, the hazards, the risks and how these are addressed.

In general, the structural engineer should consider:

- Opportunities to use unprotected steel by 'fire engineering' analysis, addressing natural fire.
- Systems as partially encased columns and beams or integrated floors that allow ISO fire resistance up to R180.
- Influence of service integration on the fire protection system, and appropriate solutions such as intumescent coatings on cellular and other fabricated members.
- Influence that site-applied protection may have on programme implications, particularly if spray applied.
- Requirements for the final appearance of exposed steelwork when choosing a fire protection system.
- Schemes, which have fewer beams to fire protect.

2.8 Thermal performance

Thermal insulation through the building envelope is traditionally the Architect’s responsibility, the structural engineer must be intimately involved in the development of appropriate details and layout. Supporting systems for cladding may be more involved, again involving eccentric connection to the supporting steelwork. Steel members that penetrate the insulation, such as balcony supports, need special consideration and detailing to avoid ‘thermal bridging’. Thermal bridges not only lead to heat loss, but may also lead to condensation on the inside of the building.

2.9 Loading

The principal types of loading that need to be considered in the design of multi-storey buildings are:

- Dead
- Imposed (Long term and short term)
- Wind
- Snow

The main loads in multi storey building are generally dead loads in combination with imposed loads. The wind loads are generally transmitted from the facades via the slabs to the concrete core enveloping the staircases and elevators. Another less common solution in this building types are bracing systems in the facades as well as sway frame construction.

The load combinations are given in EN1990. The recommended values for imposed loads are given in EN1991-1-1 and in EN1991-1-2 in case of the accidental action “Fire”. The snow loads are given in part 1-3 and the wind action in part 1-4 of EN1991. Actions during execution can be found finally in part 1-6 of EN1991.

The main checks that have to be done are the ultimate limit state (ULS) and the serviceability limit state SLS. In order to prevent too much deflection of long span beams, they are often pre-cambered in order to prevent a deflection of the pure steel beam under death loads, whereas the imposed loads are beard by the composite beam and lead to the final deflection.

Dead loading

Generally the following dead loads should be considered in design:

Demountable partitions: 1.0 kN/m^2

Raised floors, ceiling and building services equipment: 0.85 kN/m^2

Table 2.1 gives some typical loads for multi storey buildings

Table 2.1 *Typical weights for building elements*

Element	**Typical weight**
Precast units (Spanning 6 m, designed for a 5 kN/m^2 imposed load)	3 to 4.5 kN/m^2
Composite slab (Normal weight concrete, 130 mm thick)	2.6 to 3.2 kN/m^2
Composite slab (Light weight concrete, 130 mm thick)	2.1 to 2.5 kN/m^2
Services	0.25 kN/m^2
Ceilings	0.1 kN/m^2
Steelwork (low rise 2 to 6 storeys)	35 to 50 kg/m^2
Steelwork (medium rise 7 to 12 storeys)	40 to 70 kg/m^2

Imposed loading

Imposed loading is the variable loading that is likely to be applied to the structure during its life include gravity loads due to occupants, equipment, furniture, movable partitions, stored materials and snow. The magnitude of the imposed loading will vary according to building use and the use of any specific floor (or roof) area being considered – different values are applied for a plant room or storage area, for example.

Eurocode 1 part 1-1 (EN1991-1-1) prescribes minimum imposed floor loads for different building uses. A commonly used imposed loading for a commercial office is 3 kN/m^2, whereas 2 kN/m^2 could be chosen as well. In addition 1 kN/m^2 may be added for movable partitions. In case of storage area a value of 5 kN/m^2 may be used.

3 COMMON USED FLOOR SYSTEMS

In addition to their load-resisting function, floors often act as horizontal diaphragms, ensuring horizontal loads are transferred to the vertical bracing. Floor components (the floor slab, deck units and the beams) will also require a certain fire resistance. Services may be integrated with the floor construction, or be suspended below the floor. Structural floors may have a directly-fixed floor finish, or may have a screed, or a raised secondary floor above the structure. Raised floors allow services (particularly electrical and communication services) to be distributed easily around highly serviced accommodation.

This section describes various floor systems often used in multi-storey buildings. The main characteristics of each floor system are described, with guidance on important design issues. This section does not contain detailed design procedures but directs the reader to the sources of design guidance.

The following floor systems are covered:

- Composite beams and composite cellular beams
  - with non composite steel decking (lost formwork)
  - with composite steel decking
  - with precast concrete units
- Integrated floor beams
- Non-composite beams with prefabricated hollow-core concrete slabs

Composite construction

In the following sections, design approaches are presented for composite construction, where decking must be chosen for a given span. As a connection type usually headed shear studs are used that are generally welded in the shop. While using steel decking an alternative is to weld on site the studs through the steel sheeting to the beam once they are positioned on the beams.

Steel decking may have a re-entrant or trapezoidal profile. Re-entrant decking uses more concrete than trapezoidal decking, but has increased fire resistance for a given slab depth. Trapezoidal decking generally spans further than re-entrant decking, but the shear stud resistance is reduced due to the influence of the profile shape.

To avoid working on site, the main longitudinal reinforcement are integral with the prefabricated planks.

Prefabricated hollow-core slabs are generally used with non composite beams and may represent the final slab layer.

Generally, normal weight concrete (NWC) will be used, although in some countries, lightweight concrete (LWC) is efficient and widely available.

3.1 Composite beams and composite slabs with steel decking

Description

Composite construction consists of downstand steel beams with shear connectors welded to the top flange to enable the beam to act compositely with an in-situ composite floor slab. With this connection, both the concrete slab and the steel beam are working in an optimised condition. Generally no slip occurs between the two materials; the concrete acts in pure compression and stabilises the steel beam in tension, that might else been submitted to local instability.

Framing arrangements normally require the slab to span 2 to 5 m on to secondary beams, which are in turn supported by primary beams. Another solution is to span the floor elements directly between the steel frames. While using secondary and primary beams, either only the secondary or both may be designed as composite. Edge beams can be designed as non-composite, although shear connectors may be used for structural integrity and wind loads. A typical example is shown in Figure 3.1.

The floor slab comprises a shallow ribbed steel decking and a concrete topping, which act together compositely. Slabs are typically 120 to 150 mm thick and the decking is 50-80 mm deep in a steel thickness of 0.75 to 1.25 mm.

Mesh reinforcement, normally 140 to 300 mm^2/m, is placed in the slab to enhance the fire resistance of the slab, to help distribute localised loads, to act as transverse reinforcement around the shear connectors and to reduce cracking in the slab.

The decking is normally designed to support the wet weight of the concrete and construction loading as a continuous member over at least two spans, but the composite slab is normally designed as simply supported between beams.
Pre-design software PMX, PSL and COBEC4 are available for free at the internet site www.asc.arcelor.com.

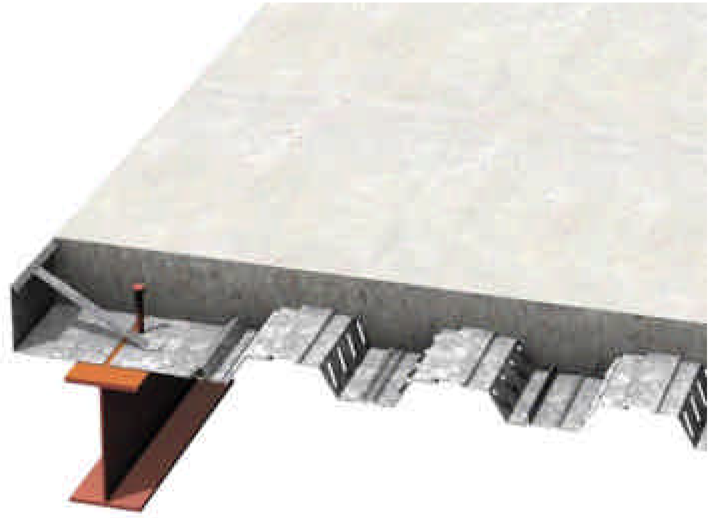


Figure 3.1 *Edge beam in composite construction*

Typical beam span range

Secondary beams: 3 m or 3.60 m spacing.

Primary beams: 6.0 m to 12.0 m.

Main design considerations for the floor layout

Secondary beams should be spaced closely enough to avoid propping the decking, as propping can be expensive and disruptive on site.

Services will need to pass under beams, and thus affect the overall floor zone.

Edge beams may be deeper than internal beams because of more onerous serviceability requirement to support the cladding. Also, the use of non-composite edge beams avoids the need for detailing special U-bars around the shear connectors, but the beams may be deeper than composite members.

Advantages

Shallower and lighter beams than non-composite construction, lightweight and economic.

Disadvantages

Deeper overall floor zone than shallow floor systems.

Services integration

Main heating and ventilation units can be positioned between beams, but ducts pass below beams. Services may be passed through local holes in the web up to 600 mm diameter.

Governing design criteria for beams

Bending resistance will usually govern for S235 or S275 steel. Increasing the span leads to the use of high strength steel, of grades S355 and S460, for which the deflection then mainly governs.

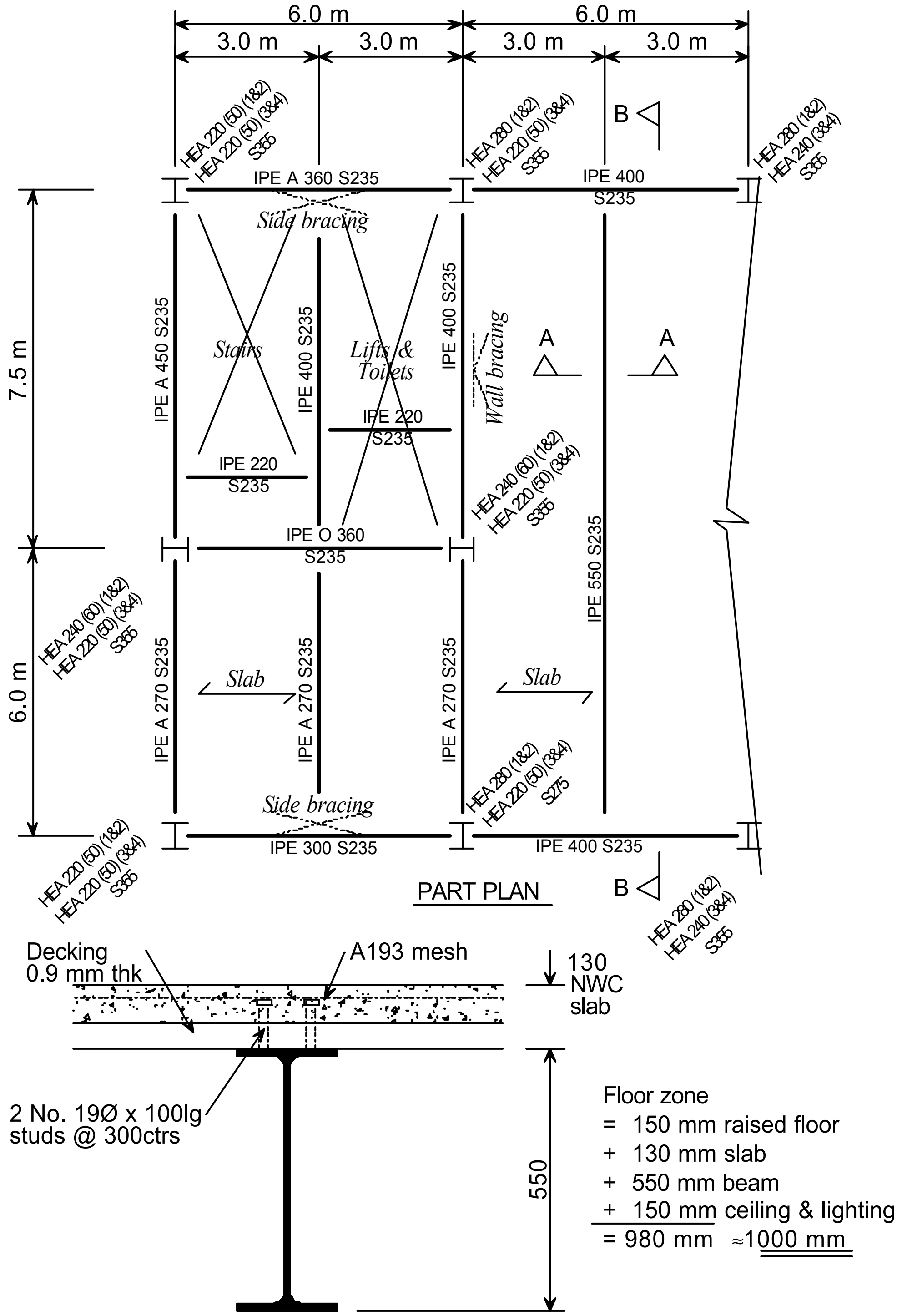


Figure 3.2 *Long-span composite beam ~ example of floor steelwork arrangement for 4-storey rectangular plan building*

Governing design criteria for decking/slab

Strength or deflection of the decking in the construction condition.

Fire resistance (affects concrete cover to the decking and mesh reinforcement size).

Design approach

1. Assume beams of 12 to 16m span at 2,4 to 3 m spacing. If main beams are used, they may span 2 to 3 times the secondary beam

spacing.

2. Choose decking and slab, using decking manufacturer's load tables or software. Assume un-propped decking during construction. Ensure the chosen slab depth and reinforcement meet the fire resistance required.

3. Use shear connectors at 300 mm spacing for secondary beams (to suit deck rib spacing), and at 150 mm spacing on primary beams. The orientation of the decking will differ between secondary and primary beams.

Typical section sizes

Composite beam depth (steel beam) ≈ span/24
IPE240 S275 for 6 m span and 3.0 m spacing (secondary beam)
IPE300 S355 for 7.5 m span and 3.75 m spacing (secondary beam)
IPE360 S355 for 7.5 m span and 7.5 m spacing (primary beam)
Usually one serial size deeper for edge beams

Grade of steel

Secondary beam and edge beams: Usually S235 or S275 steel.

Primary beam: S355 steel.

Overall floor zone

Typically, the overall floor zone is 1200 mm for 9 m grid with 150 mm raised floor and air conditioning below the beams. The overall floor zone is illustrated in Figure 3.3

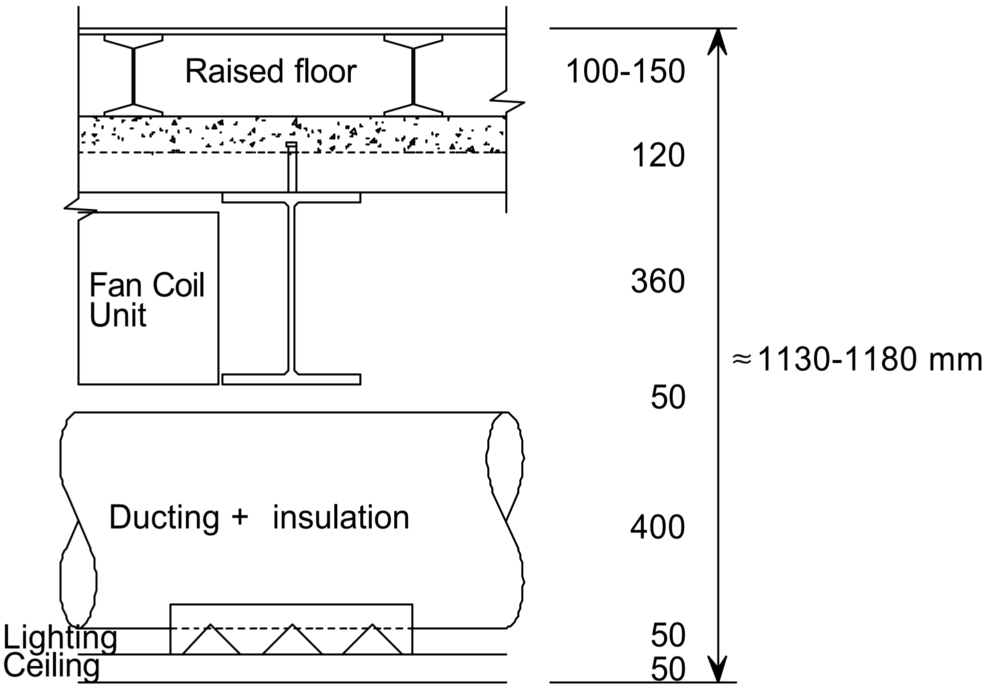


Figure 3.3 *Overall floor zone ~ typical short-span composite construction*

Type of concrete

Either normal weight concrete (NWC), 2400 kg/m^3 dry density, or lightweight concrete (LWC), 1850 kg/m^3 dry density, can be used.

NWC has better sound reduction, so is better for residential buildings, hospitals, etc.

LWC is better for overall building weight/foundation design, larger span capability of slab, and has better fire insulating properties, enabling thinner slabs (10 mm less) to be used. It is not available in all parts of Europe.

Grade of concrete	Use C30 as a minimum. Use C40 for wearing surfaces.	
Fire protection	Beams (typically):	
	Intumescent coating:	1.5 mm thick for up to 90 minutes fire resistance
	or	
	Board:	15 - 25 mm thick for up to 90 minutes
	Columns (typically):	
	Board:	15 mm thick for up to 60 minutes
	Board:	25 mm thick for 90 minutes
Connections	Simple (non-moment resisting) connections: double angle cleats, partial depth flexible endplates or fin-plates.	

3.2 Integrated floor beams

Description

Integrated floor beams are shallow floor systems comprising asymmetric beams supporting generally hollowcore concrete elements. Besides the "Integrated Floor Beam" (IFB) and the "Slim Floor Beam" (SFB) systems, other types of asymmetrical systems exist. The IFB system is build up by cutting an IPE or HE section in two equal T stubs and by welding an additional plate to the web. For the SFB system the rolled section is not cut but a plate is welded underneath the lower flange of an HE section, see Figure 3.4. This plate of typically 15mm extends by at least 100 mm each side. The prefabricated concrete elements are put on the lower flange and are generally designed as non composite. A structural concrete topping with reinforcement is recommended to tie the units together in order to react as diaphragm. The topping thickness should cover the p.c. units by at least 30 mm. If used without a topping, reinforcement should be provided through the web of the beam to tie the floor on each side of the beam together, to meet robustness requirements (diaphragm effect).

A composite integrated beam can be achieved by welding shear connectors (normally F 19 mm h = 70 mm) to the top flange of the steel section. Reinforcement is then placed across the flange into slots prepared in the precast units, or on top of shallow precast units. If the steel beams are to be designed compositely, the topping should cover the shear connectors by at least 15 mm, and the precast units by at least 50 mm.

Beam span arrangements are normally based on a 5-7.5 m grid (9.0 m can be reached using long span steel sheeting as floor system), with a slab span of 6-11 m and depth of 200-350 mm (see Figure 3.5). With integrated floor beams, slab span is generally larger than beam span. Reinforcing bars (16–25 mm dia) in the concrete filled openings of the slab give additional fire resistance.

A range of integrated floor sections is commonly used between 200 and 370 mm depth, using a thickness of the bottom plate of 10-40mm.

Edge beams can be IFB/SFB sections with modified geometry or RHS beams, which comprise a rectangular rolled hollow section (RHS) with a flange plate welded underneath. Edge beams are often designed as non-composite, with nominal shear studs provided to meet robustness requirements. These studs are usually aligned with openings cast in the precast units. Composite edge beams require careful detailing of U-bar reinforcement into slots in the units.

Mesh reinforcement is placed in the concrete layer over the steel section. If the top flange of the IFB/SFB is level with the surface of the concrete, the slabs each side of the IFB/SFB should be tied together to meet robustness requirements, normally by reinforcement (typically T12 bars @ 600 mm centres) passed through the web or "Hat rebars" passing over the IFB/SFB section. IFB/SFB are normally designed as non-composite. (Note that a cover to the IFB/SFB of at least 30 mm is recommended as the reinforcement cannot be accommodated easily in less than 30 mm depth).

Pre-design software IFB-Win is available for free at the internet site www.asc.arcelor.com.

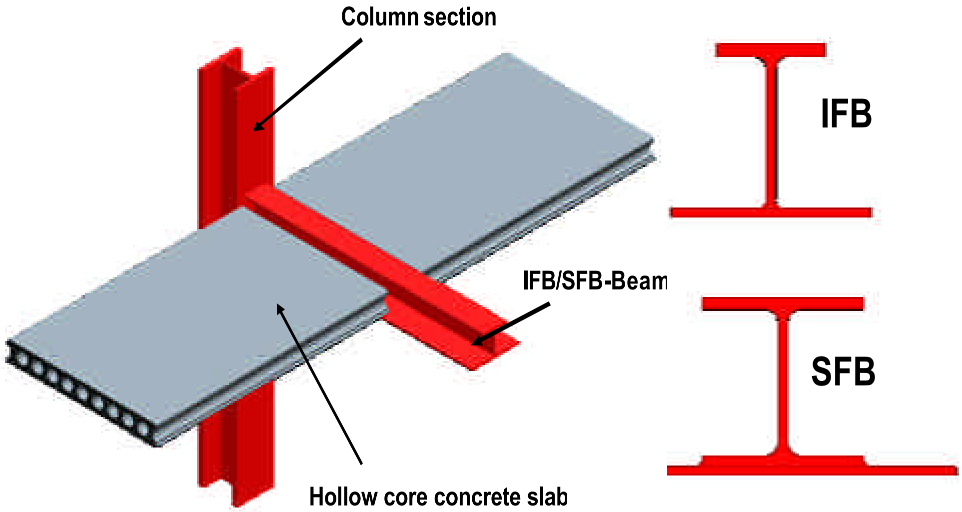


Figure 3.4 *Typical integrated floor beams*

Typical beam span range 5 m to 7.5 m generally, although 10 m spans can be achieved with deeper p.c. units.

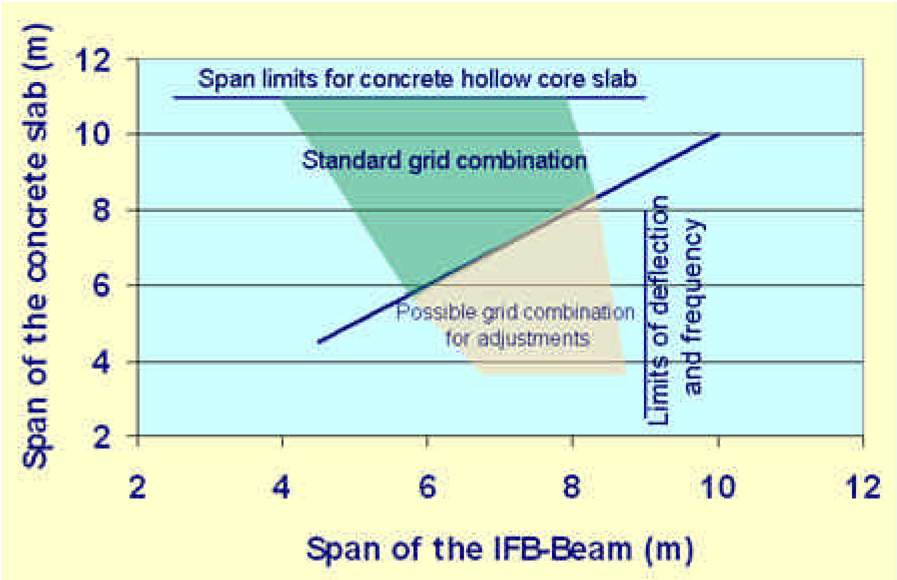


Figure 3.5 *Range of application for IFB-Beams*

Main design considerations for the floor layout

Ideally, the span of the precast units and the beam span should be optimised. Beams loaded on one side only are relatively heavy because of torsional loading. Torsional loading during construction will need to be checked. A central spine beam with precast units spanning to downstand edge beams will generally be more economic than parallel transverse beams. RHS or IFB/SFB edge beams may be used. Composite edge beams require careful detailing of U-bars around the shear connectors and into the precast units or structural topping – non-composite edge beams are preferred.

Slab depth is influenced by the concrete cover to the deck (mainly for fire resistance), cover to the IFB/SFB (30 mm minimum), and cover to the edge beam. Generally IFB/SFB are designed as non-composite.

Detailing of connections around columns should be considered, as the IFB/SFB flanges are wider than the column and may need notching.

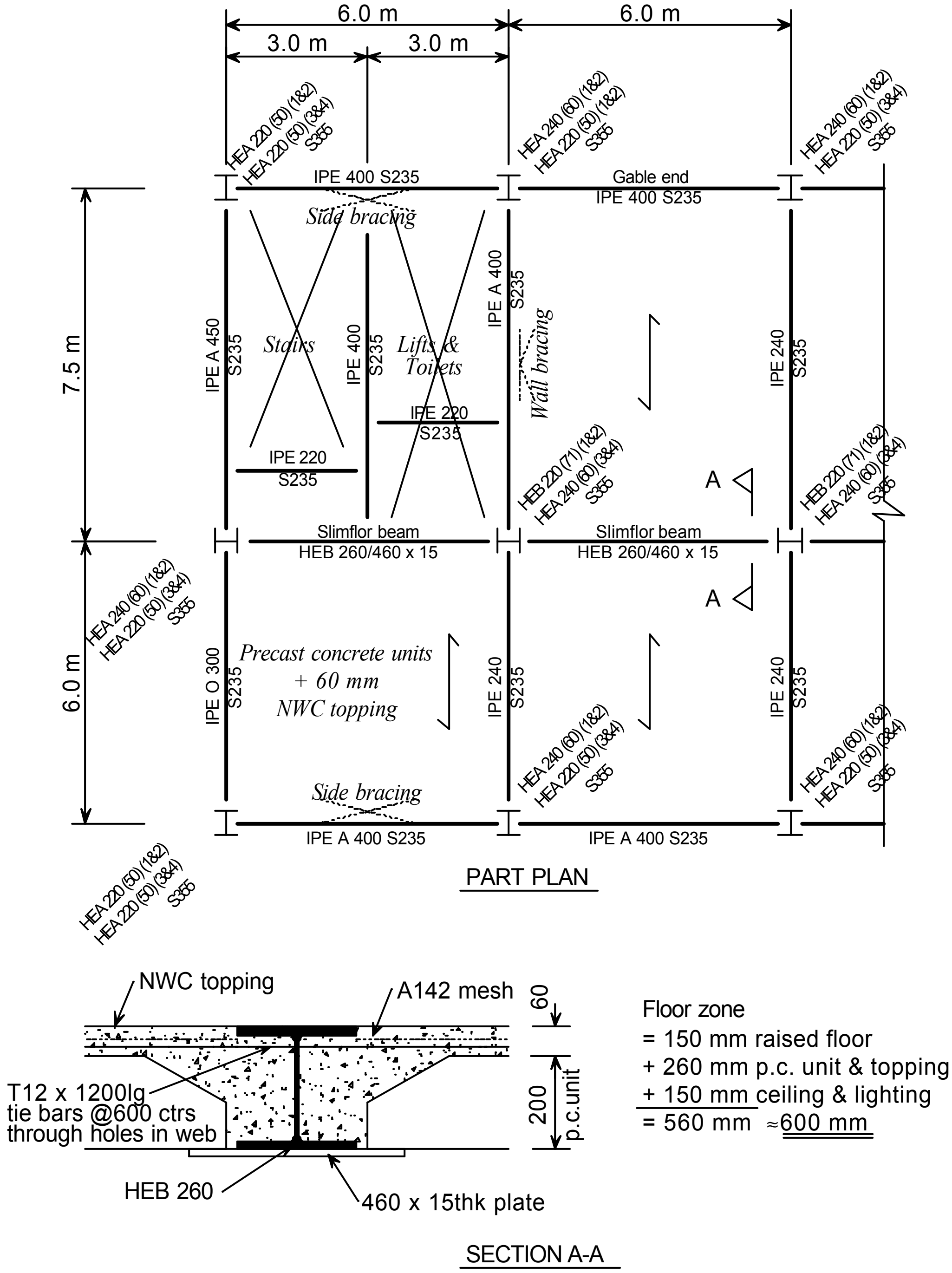


Figure 3.6 *Integrated beams and precast concrete slabs with concrete topping flush with top flange*

Advantages Beams normally require no fire protection for up to 60 minutes fire protection.

Shallow floor zone – reduction in overall building height and cladding. Flat soffit allows easy service installation and offers flexibility of internal wall positions. Soffits can be exposed.

Integrated floor beams consist in a "dry system" with high level of prefabrication and fast erecting time.

Low steel consumption.

Disadvantages The span is limited.

Extra fabrication is involved in welding the plate to the UC or HE sections. Connections require careful detailing as the plate is wider than the column.

Precast concrete units involve more individual lifting operations than steel decking, which is delivered and erected in bundles. The erection sequence requires access for installation of the concrete units.

Services integration Unrestricted distribution of services below the floor.

Governing design criteria Critical checks are usually the torsional resistance, combined torsion and lateral torsional buckling resistance (LTB) in the construction condition (when loaded on one side only), or LTB in the construction condition (with loads on both sides).

Deflection may be critical for shallow beams.

Governing design criteria for precast units Shear resistance of hollow core units (for high applied shears, or for propped construction, consult p.c. concrete manufacturer).

Shape/dimensions of the end of the p.c. unit (rectangular or chamfered) to allow sufficient gap for free flow of concrete around the steel section (60 mm minimum between the concrete units and the steel is recommended).

Detailing of transverse reinforcement around the beam shear studs and into the precast units, where composite action or improved fire resistance is required

Length of the unit for end bearing (75 mm minimum for non-composite action and 60 mm minimum for composite action is recommended).

Design approach

1. Use 6 m, 7.5 m or 9 m grid. The p.c. concrete units generally span the longer distance in a rectangular floor grid.
2. Choose precast concrete hollow section from manufacturer's data. Ensure these meet the required fire resistance. A recommended maximum span over depth ratio is 35 to achieve sufficient shear resistance.
3. Design the IFB/SFB beam using software. Beams may be non-composite or composite. Check that the cover to composite beams is at least 15 mm over the studs. If non-composite, allow for ties between the precast units through the web.
4. Design the edge beams – either RHS, IFB/SFB beams loaded on one side or downstand sections. Composite edge beams require U-bar transverse reinforcement.

Typical section sizes SFB – HEA240 + 15mm plate, beam span 5m, slab span 6m

SFB – HEB280 + 15mm plate, beam span 6m, slab span 8m

SFB – HEB320 + 15mm plate, beam span 8m, slab span 8m

IFB – ½ IPE500 + 20mm plate, beam span 5m, slab span 6m

IFB – ½ HEA500 + 20mm plate, beam span 6m, slab span 8m

IFB – ½ HEB600 + 20mm plate, beam span 8m, slab span 8m

Precast units: choose 150 mm depth for 6m span, 200 mm depth for 7.5 m span and 260-300 mm depth for 9 m span.

Grade of steel IFB/SFBs are available in all common steel grades steel, S235-S460.

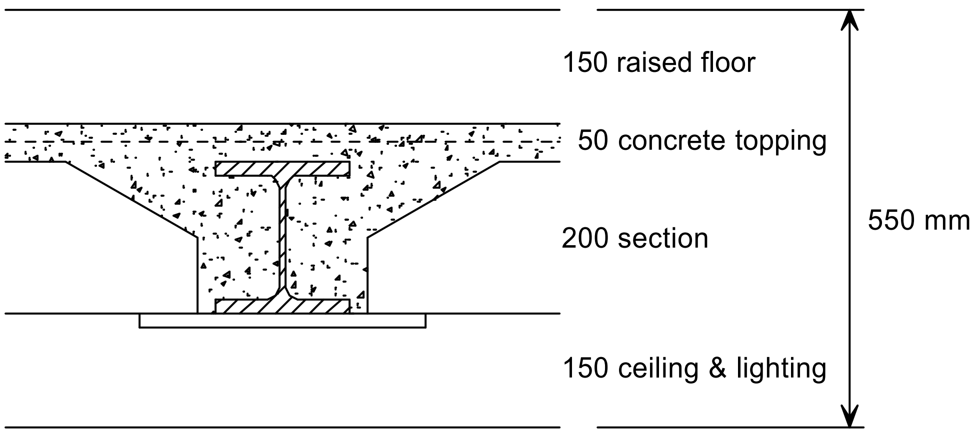
Overall floor zone 600 mm with small services (with raised floor).

1000 mm with air conditioning (with raised floor).

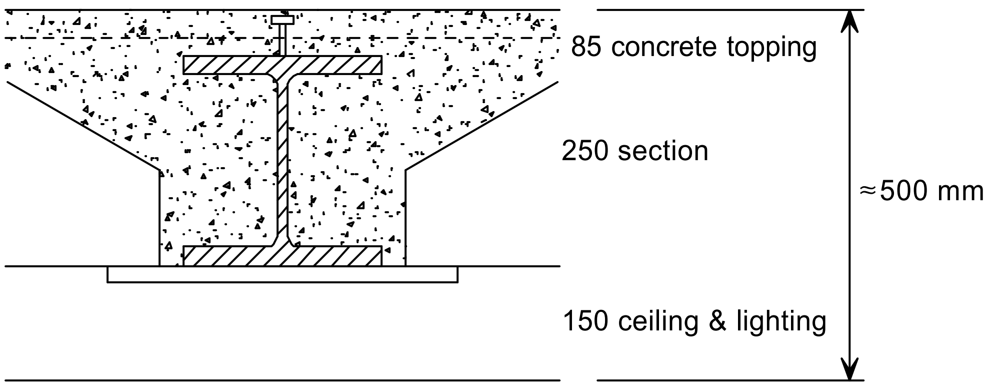
Fire protection The concrete encasement around the beam is normally sufficient for up to 60 minutes fire resistance without additional protection.

For 90 minutes fire protection, an intumescent coating or board protection to the flange plate could be chosen. Correct detailing of transverse reinforcement is required, particularly for hollow core units, where filling of the cores adjacent to the beam is necessary.

Connections Integrated beams require end plate connections (typically, 6 or 8 bolt) to resist torsional loads. RHS edge beams often use extended end plate connections to minimise the connection width.



(a) Non-composite integrated floor beam with raised floor



(b) Composite integrated floor beam without raised floor

Figure 3.7 *Integrated floor beams - Typical cross-section*

Longer span variants of Integrated floors have been developed, such as in Figure 3.8 using solid or SHS members as ties. Spans of 9 to 12 m can be achieved.

Figure 3.8 *Long span version of Integrated floor beams, used in the Luxembourg Chamber of Commerce*

3.3 Cellular composite beams with composite slab and steel decking

Description

Cellular beams are beams with circular openings at regular spacings along their length. The beams are either fabricated from three plates, or made by cutting and re-welding from hot rolled steel sections. In this case an increase of the profiles depth without any addition in material is obtained. Openings, or 'cells', are normally circular, which are ideally suited to circular ducts, but can be elongated, rectangular or hexagonal. In case of high shear efforts near the supports or point loads, cells can easily be filled or stiffened. The size and spacing of the openings is governed by required cell diameter as well as by the present stresses.

Cellular beams can be arranged as long-span secondary beams, supporting the floor slab directly, or as long-span primary beams supporting other cellular beams or I section secondary beams.

Pre-design software ACB is available for free at the internet site www.asc.arcelor.com.

Typical beam span range

10 – 18 m for cellular beams as secondary beams.

Figure 3.9 *Long-span secondary cellular beams with regular circular openings*

Main design considerations for the floor layout

Secondary beams should be spaced about 2 - 4m in order to avoid propping of the decking during concreting.

Large (elongated or rectangular) openings should be located in areas of low shear, e.g. in the middle third of span for uniformly loaded beams.

Integration of the services within the beam depth to minimise the overall floor zone.

Advantages

Long, column-free floor spans with efficient use of steel.

Relatively lightweight beams compared to other long-span systems.

Services can be integrated within the floor zone.

Pre-camber can be introduced during the fabrication of the members.

Reduction of the overall floor height and consequently of the building height

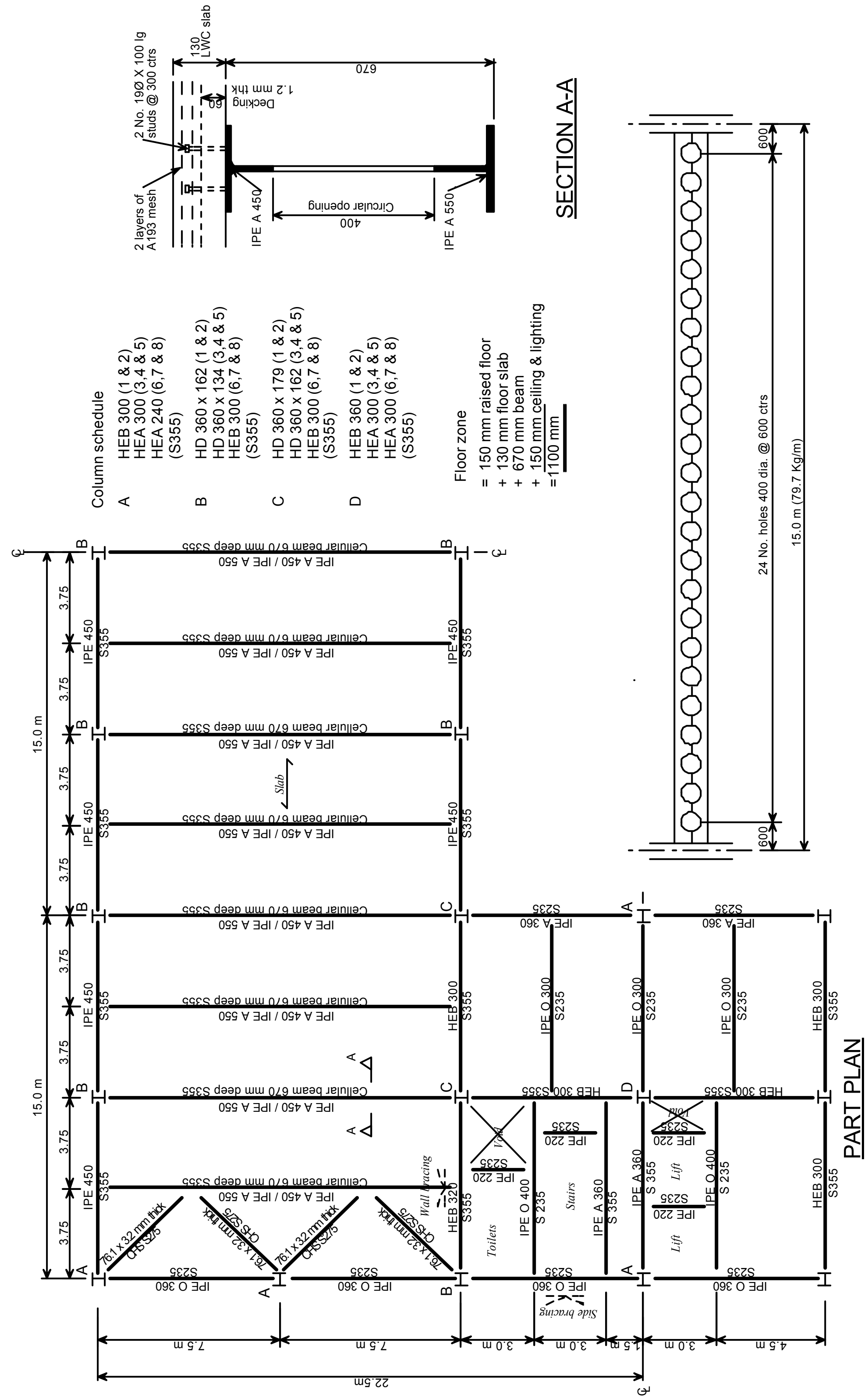


Figure 3.10 *Cellular beams (long-span secondary beams) and composite slabs – example of floor steelwork arrangement for a 4 storey rectangular plan building*

Disadvantages Cost-effectiveness starting from 12 metres length

Services integration

Regular openings in the web allow ducts to pass through the beams as shown in Figure 3.11. Openings diameter can be adapted following the services requirements and should allow for any insulation around the services. Web openings should be aligned through the beams along the building.

Governing design criteria for beams

Web post buckling between openings and Vierendeel bending around the cells

Opening size is 60 - 80% of the beam depth. Stiffeners may be required for elongated openings.

Governing design criteria for decking/slab

Strength or deflection of the decking in the construction condition.

Fire resistance (affects the concrete cover to the decking and mesh reinforcement size).

Design approach

1. Design cellular beams as long-span secondary beams at 3 – 4 m spacing, supported by primary beams on a 6 m, 7.5 m or 9 m column grid

2. Choose the decking and slab, using decking manufacturer's load tables or software. Assume LWC unless there is a directly-bonded floor covering. Ensure the chosen slab and reinforcement meet the fire resistance required.

3. Design the cellular beams using manufacturer's software. Use a centre-centre spacing of cells of not less than 1.3 × opening diameter. Use shear studs placed in every steel sheeting rib. As the services are likely to be integrated within the structure, ensure cell sizes and positions are agreed with the services engineer.

Typical section sizes

600 mm deep cellular beams for 15 m span at 3.75 m centres.

(Beam + slab depth) ˜ span/18-20.

Grade of steel

S355 generally

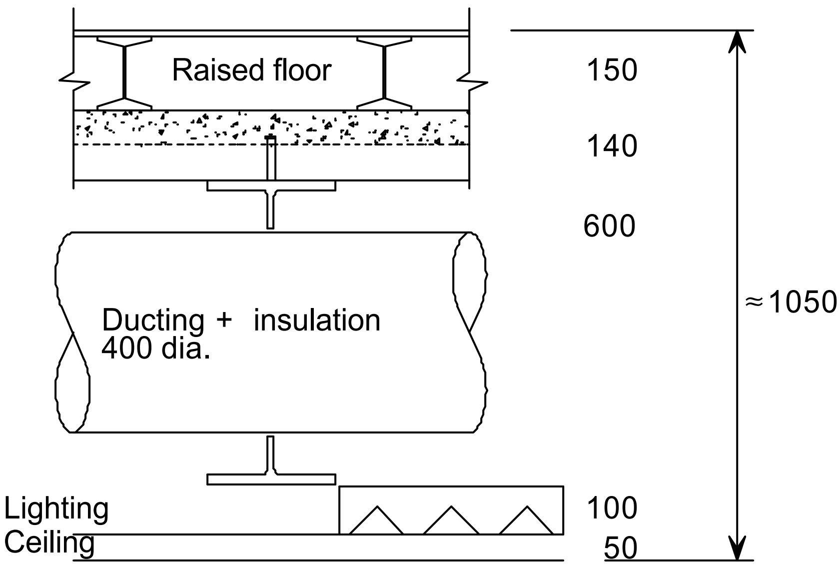


Figure 3.11 *Cellular beam - Typical cross-section showing services integration*

Type of concrete

Either normal weight concrete (NWC), 2400 kg/m^3 dry density, or lightweight concrete (LWC), 1850 kg/m^3 dry density, can be used effectively.

Overall floor zone 1050 mm for 15 m span with regular 400 mm opening.

Fire protection Intumescent paint, is often applied on site but a trend toward off-site application can be noticed in some countries.

3.4 Composite beams with precast units

Description This system consists of steel beams with shear studs welded to the top flange. The beams support precast concrete units with a structural concrete infill over the beam between the ends of the units, and often with an additional topping covering the units (recommended). The precast units are either hollow core, normally 150 - 260 mm deep, or solid planks of 40 mm to 100 mm depth.

At the supports, the precast units are positioned on top of the flange. Deeper p.c. units are either chamfered on their upper face or notched down - to allow a thicker topping depth to fully encase the shear connectors. Narrow slits are created within the units during the manufacturing process to allow transverse reinforcement to be placed across the beams and be embedded in the precast units for approximately 600 mm either side (see Table 3.1 for recommended sizes). For hollow core units, the top of a number of discrete (not adjacent) cores should to be broken out during manufacture so that reinforcement can be placed and concreted into position.

The shear studs and transverse reinforcement allow the transfer of the longitudinal shear force from the steel section into the precast unit and the concrete topping, so that they can act together compositely. Composite design is not permitted unless the shear connectors are situated in an end gap (between the concrete units) of at least 50 mm. Stud capacity depends on the degree of confinement of the stud. LWC or NWC (10 mm aggregate) may be used for the topping. Hollow cores should be back-filled at the supports for a minimum length equal to the core diameter to provide for effective composite action and adequate fire resistance.

Edge beams are often designed as non-composite, with nominal shear studs provided to meet robustness requirements. Composite edge beams require careful detailing of U-bar reinforcement into slots in the units, and a greater minimum flange width.

Minimum flange widths are required to provide a safe bearing length for the precast units and sufficient gap for effective action of the shear studs – see below for minimum recommended values.

Temporary bracing providing lateral restraint is often required to reduce the effective length for lateral torsional buckling of the beam during the construction stage, when only one side is loaded. Full torsional restraint in the temporary condition may be difficult to achieve, unless deep restraint members with rigid connections are used, or by developing 'U-frame action' involving the beams, the restraint members and rigid connections.

Pre-design software PMX, PSL and COBEC4 are available for free at the internet site www.asc.arcelor.com.

Typical beam span range 12 - 18 m span beams, 3 - 9 m span precast units.

Main design considerations Maximise the span of the precast units.

Long span secondary beams provide sufficient minimum width to support

for the floor layout

the p.c. units (400 mm is a sensible minimum depth).

Beams that are parallel to the span of the precast units cannot be designed compositely.

Design edge beams as non-composite, but tied into the floor to meet robustness requirements.

Transverse reinforcement must be provided, as detailed in Table 3.1.

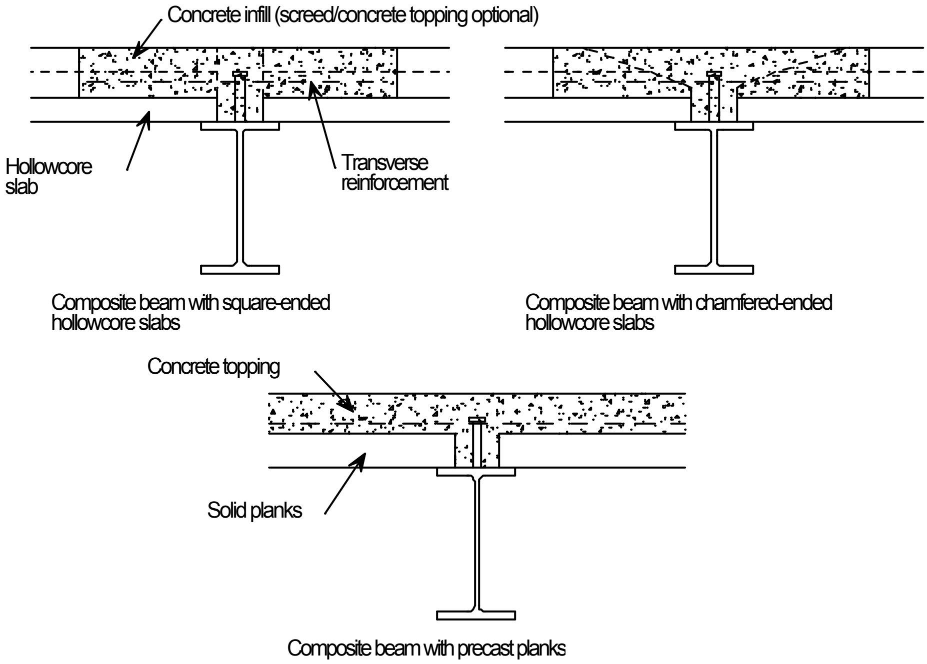


Figure 3.12 *Forms of composite beams with precast units*

Figure 3.13 *Composite floor construction with precast concrete hollow core units, showing transverse reinforcement bars placed within open cores*

Table 3.1 *Recommended bar sizes for transverse reinforcement*

Slab depth	Bar sizes
Solid Planks	T10 @ 300 mm centres plus 142mm^2/m mesh reinforcement
Hollow Core Units (up to 200 mm deep)	T16 @ 200 to 350 mm centres (unless full shear connection is provided, in which case T12 may be used)
Hollow Core Units (up to 260 mm deep)	T16 @ 200 to 350 mm centres

Advantages Fewer secondary beams, if long-span precast units are used.

Shear connectors for most beams can be welded off site, enabling larger stud diameters to be used and fewer site operations. It is usually convenient to weld studs to edge beams on site.

Disadvantages The beams are subject to torsion and may need additional stabilising measures during the construction stage.

Precast units need careful detailing for adequate concrete encasement of shear connectors and installation of transverse reinforcement.

More individual lifting operations compared to the erection of decking, and the erection sequence requires access for installation of the concrete units.

Services integration Main service ducts are located below the beams with larger equipment located between beams.

Governing design criteria for beams Minimum flange width for bearing and studs, stud size (site-welded or factory-welded)

The critical check is often torsional resistance and twist, or combined torsion and lateral torsional buckling resistance (LTB) in the construction condition (with loads on one side only).

Minimum flange width for bearing:	Minimum beam widths:
40 or 100 mm deep solid unit	Internal beam – 180 mm
	Edge beam – 210 mm
Hollow core unit	Internal beam – 180 mm
	Edge beam – 210 mm

Non- composite edge beam – 120 mm minimum

Governing design criteria for precast units Shear resistance of hollow core units.

Detailing of beam transverse reinforcement into units, where composite action or increased fire resistance is required.

Typical section sizes

Beams:

Typical rolled serial size is IPE 300 to IPE 600 for precast units with chamfered end and shop-welded connectors. HE section may be used as well.

Precast planks

Maximum span without propping are of 5 m

40 mm deep with 140mm final slab for 7 m span

60 mm deep with 160mm final slab for 11 m span

Precast hollow core units: (approximate):

150 mm deep for 6 m span @ 2.5 kN/m^2

200 mm deep for 7.5 m span @ 3.0 kN/m^2

250 mm deep for 9 m span @ 5.0 kN/m^2

Design approach

1. A 9 m grid is the optimum for this system.
2. Choose precast concrete planks from manufacturer's data. Ensure these meet the required fire resistance. Longer spans are likely to be composite. Note the overall depth.
3. Design the steel beam, using software or SCI publication P287 Design of composite beams using pre cast concrete slabs
4. Design edge beams – as non-composite to avoid costly transverse reinforcement.

Grade of steel

S235 to S460

Overall floor zone

900 mm including ceiling (see example below)

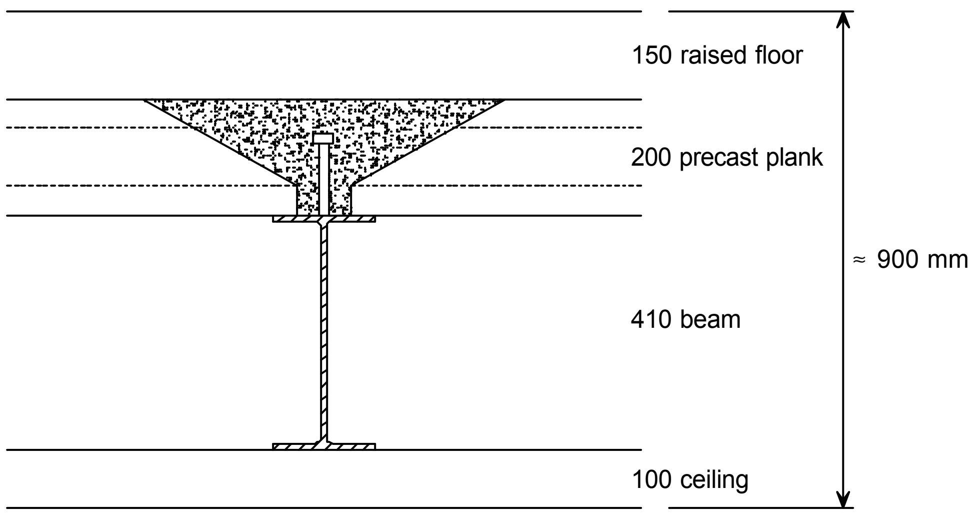


Figure 3.14 *Composite beam and precast concrete unit – typical cross-sections*

Fire protection

Spray, board or intumescent coating to beam or partially encased beams.

Transverse bars must be carefully detailed into the precast units – extending 600 mm into each unit. For 90 or 120 minutes fire resistance, a 50 mm (minimum) concrete topping is required.

Connections

Full depth end plate connections (welded to the beam flanges) to resist torsional loading.

3.5 Non-composite beams with precast units

Description

Precast units may be supported on the top flange of the steel beams, or, to reduce construction depth, supported on 'shelf' angles. Shelf angles are bolted or welded to the beam web, with an outstand leg long enough to provide adequate bearing of the precast unit and to aid positioning of the units during erection. Precast concrete units are generally grouted in position. The units may have a screed (which may be structural), or may have a raised floor. The precast units are mostly hollow core, normally 150-260 mm deep, or solid planks of 75 mm to 100 mm depth could be used.

Temporary lateral bracing is often required to limit the effective length for lateral torsional buckling of the beam during the construction stage when only one side is loaded.

In order to meet robustness requirements, mesh and a structural topping may be required, or reinforcement concreted into hollow cores and passed through holes in the steel beam web. Tying may also be required between the concrete units and the edge beams.

Pre-design software PSL is available for free at the internet site www.asc.arcelor.com.

Typical beam span range

6 m and 7.5 m grids are common for both beams and precast units. However the span of steel beam may be much higher.

Main design considerations for the floor layout

Construction stage loading (precast planks on one side only) must be considered. Temporary bracing may be required.

Beams loaded on one side only in the permanent condition should either be avoided, or designed for the applied torsional moment.

Advantages

A simple solution where beam depth is not critical.

Disadvantages

The beams are subject to torsion and may need stabilising during the construction stage.

More individual lifting operations compared with the erection of decking, and the erection sequence requires access for installation of the concrete units.

Services integration

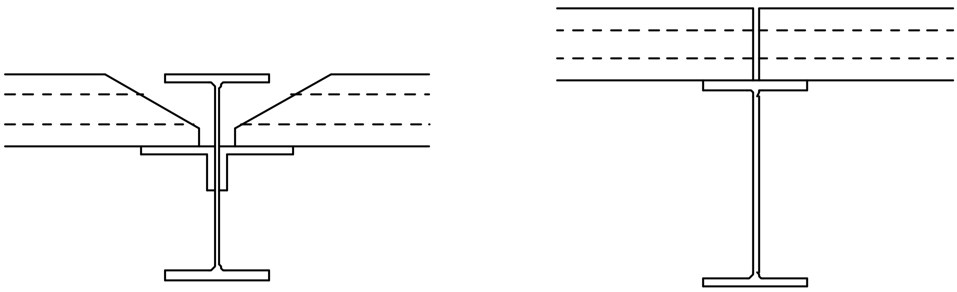
Main service ducts are located below the beams with larger equipment located between beams.

Governing design criteria for beams

When the top flange of a beam supports precast planks, the minimum flange width is 200 mm to allow for minimum bearing and a 30 mm gap between the p.c. units.

Shelf angles should project at least 50 mm beyond the beam flange. When shelf angles are provided, 25 mm clearance is required between the end of the concrete unit and the beam flange, as shown in Figure 3.17.

The critical beam check is often torsional resistance, or combined torsion and lateral torsional buckling resistance (LTB) in the construction condition (with loads on one side only).



(a) Units sitting on shelf angles

(b) Units sitting on top of downstand beam

Figure 3.15 *Floor construction with precast concrete units in non-composite construction*

Figure 3.16 *Precast concrete units on steelwork*

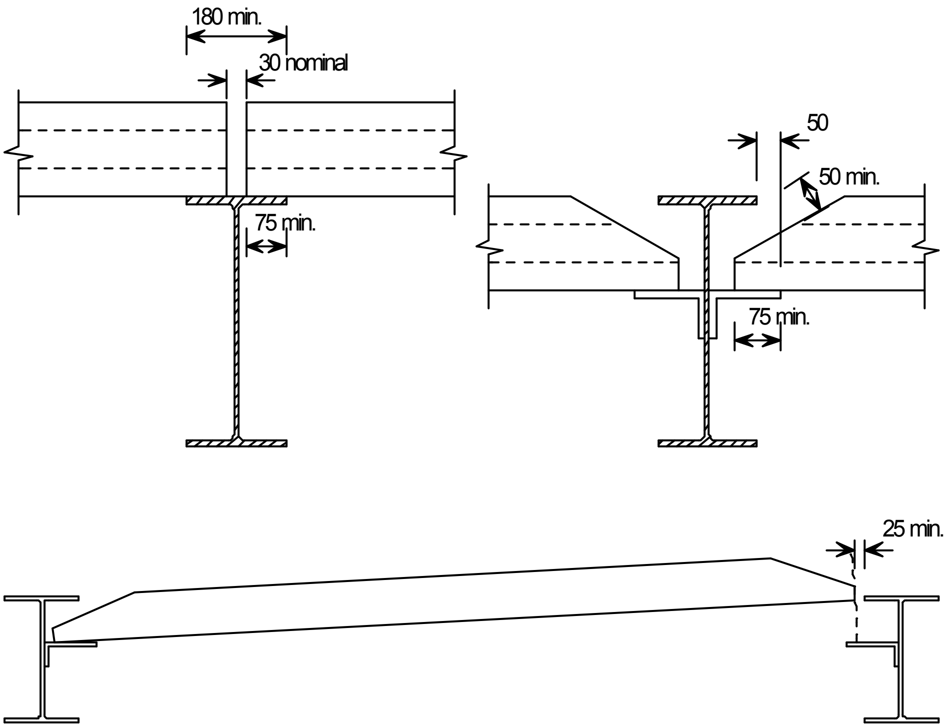


Figure 3.17 *Bearing and clearance requirements for precast units*

Design criteria for precast units Shear resistance of hollow core units.

Typical section sizes Beams:

When supporting precast planks on the top flange, the minimum rolled serial size is IPE 400.

Design approach

1. Try 6 m or 7.5 m grid using 150 mm deep units for 6 m span and 200 mm deep for 7.5 m span.
2. Choose precast concrete planks from manufacturer's data. Ensure these meet the required fire resistance.
3. Design the steel beams, using software, or by simple manual calculation of the bending moment and deflection.
4. Check the temporary construction condition, and consider temporary bracing as part of the erection method.

Grade of steel S235 to S460

Overall floor zone Approximately 800 mm including ceiling (for 7.5 m grid)

Fire protection Spray, board or intumescent coating to beam. Shelf angle beams can achieve 30 minutes fire resistance by up-turning the angles so that they remain relatively cool in fire.

Connections Full depth end plate connections (welded to the beam flanges) are required, as the beams usually resist torsional loads in the construction condition.

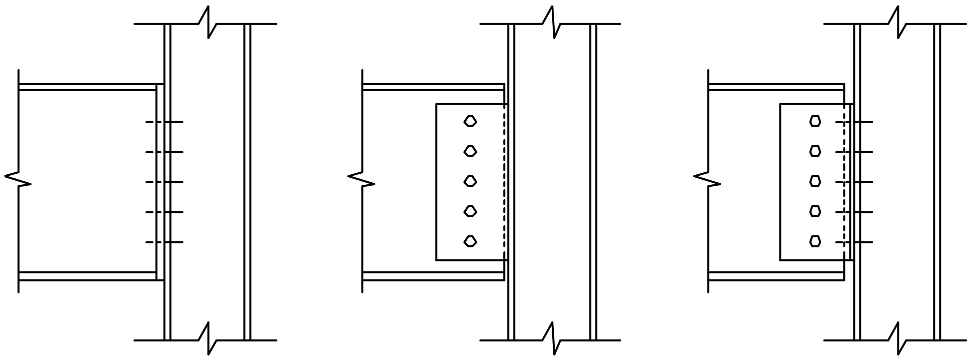
4 BEAM CONNECTIONS

All the floor systems reviewed in the previous section utilise simple connections, which are not assumed to develop significant moments. To realise this assumption in practice, the connection details must be ductile, in order to accommodate the rotation that develops at the connection.

Full depth connections are provided for floor members that are subject to torsion, such as asymmetric beams for integrated floor systems. For any floor solution, the possibility of torsional loading in the construction stage should be checked, as connections with torsional resistance, or temporary restraints may be required. In full depth connections, an end plate is welded to the beam flanges in addition to the web.

4.1.1 Simple connections

When connections are not subject to torsion, simple (vertical shear only) connections are usually detailed. Standard connections are used, with the choice of detail left to the steelwork contractor. The standard connections are the flexible end plate, a fin plate or double angle cleats, shown in Figure 4.1.



Flexible end plate Fin plate Double angle cleat

Figure 4.1 *Standard beam connections*

In general, flexible end plates are the generally used for beam-column connections. Connections to hollow sections are also straightforward, with the flexible end plate and double angle cleat connections using proprietary ‘blind’ fixings, or bolts using formed, threaded holes.

Beam to beam connections also utilise the standard details, although the secondary beam will need to be notched, as shown by a flexible end plate example in Figure 4.2.

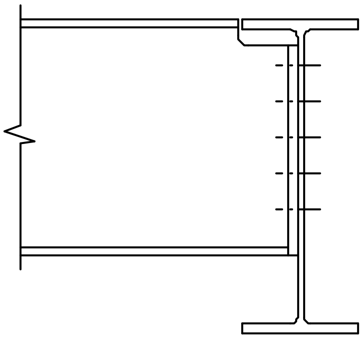
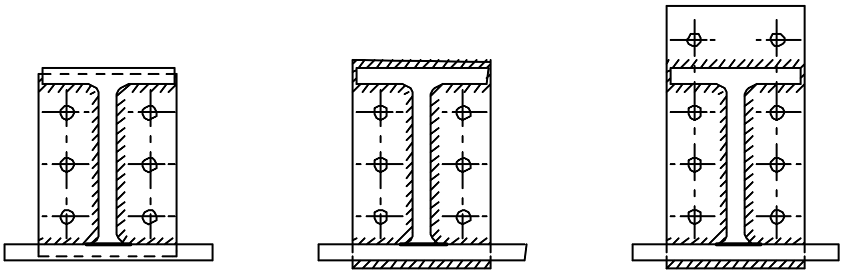


Figure 4.2 *Beam to beam connection*

4.1.2 Full depth end plates

When connections are subject to torsion, the connection is usually fabricated with a full depth end plate, as shown in Figure 4.3. In these connections, the end plate is welded around the full profile of the member.



SFB end plate details

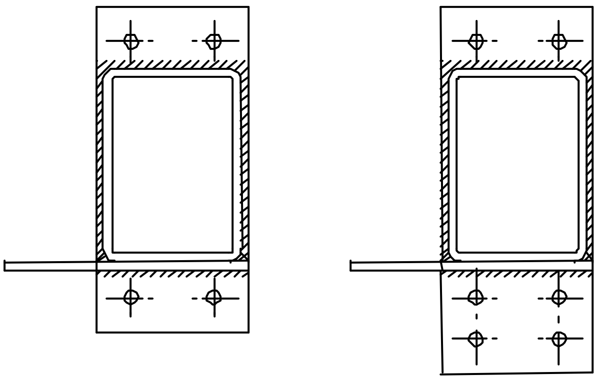


Figure 4.3 *Full depth end plates for Integrated floor and edge beams*

It is usual practice for the steelwork contractor to design the connections and the designer should provide connection shears and torques for the relevant stages, i.e. during construction and in the final state. This is because for many members, torsion may be a feature at the construction stage, when loads are only applied to one side of the member. Other members, such as edge beams, will be subject to torsion at all stages. In this case, both the welds and the bolt group must be checked for the combined effects of the applied torsion and vertical shear.

5 ADDITIONAL EUROPEAN PRACTICES

5.1 National best practice in France

5.1.1 Composite steel cellular beams and slabs for office buildings, TERRELL ROOKE.

The TERRELL ROOKE design office has promoted the use of composite cellular beams to be used for long span office platforms. The ratio useful m² per person compared to gross m²/person is high by reducing all non efficient m² and intermediate supports. A ratio of 90/10 is reached where usually a ratio of 75/25 is current.

In the proposed system the design office do not try to realize the thinnest structural slab but try to design for the most efficient structural slab + service void. Air conditioning, service zone and electric networks are positioned between the structural beams. Beams interdistances as well as beams height are optimized and span can reach up to 18 m without any intermediate supports. This allows for open space platform organization and efficient offices. Figure …. shows a typical slab arrangement. 40 to 50 mm void is needed for this application. The approach needs efficient cooperation between the structural design team and the services design team. Openings in the cellular beam shall be relevant to the service maximum dimension.

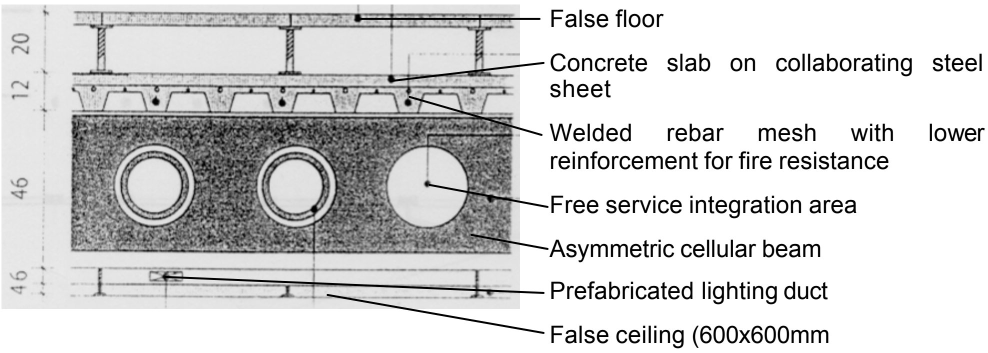


Figure 5.1 *Typical section of the slab (beam span = 17m)*

Cellular beams are from Westok; Arcelor… made from rolled sections or from fabricated sections. Steel grade are usually S355. Spans of 12 meters are current and 18 meters has been reached in an office building in Paris. All materials are available on the market.

As an example: for a load of 350 kg/m² (office load), a span of 12 meters, an interdistance between beams of 4 m, a composite slab of 14 cm thick, the height of the cellular beam is 360 mm, composed from half a rolled section HEB 240 for the top and from half a rolled section HEB 340 for the bottom. Steel weight is around 35 daN/m². Rapid calculations, classical composite beam and false ceiling compared to the proposed integrated service void have showed that 180 mm deep can be gained.

These systems of slabs are also lighter than the corresponding concrete / composite slabs. It is well suited for refurbishing operations and there is no need to strengthen ground foundations. There is no bearing wall and facade can be lighter than original one.

68 Boulevard Haussman – Paris | 7 Place d'Iéna - Paris

68 Boulevard Haussman – Paris | 54 Boulevard Haussman – Paris

Figure 5.2 *4 pictures of site work*

5.1.2 COFRADAL 200

Cofradal 200 is an innovative pre-fabricated slabs system developed in France in the last years.

It is suited for light industrial and office buildings but can be used also in residential buildings.

The system is a prefabricated composite steel/concrete slab element, factory produced and ready to fix on the construction site. The elements comes completed with steel and concrete top and do not require any structural on-site concreting on the floor. Only few concreting is needed for embedding the support perimetrical joint area and a light concrete top on the floor for circulation surface. This includes also no needs for propping on site, thus allowing for simple circulation on the construction site and rapid available area for stocking during construction process. This participates to the economy of the process by reducing death periods of works due to no needs for concrete curing.

Depth is fix at a total thickness of 200 mm and weight 200 daN/m². One module width is 600 mm. Module of 1200 mm can be provided.

The slab is twice to three times lighter than an equivalent usual plain concrete slabs. This allows for less frame sections and less ground foundations. It can be used for ground slabs provided that air circulation is effective and moisture is avoided beneath the slab.

Cofradal 200 is composed of a galvanized profiled steel sheeting fy = 320 n/mm², Z275 zinc coating fitted with mineral wool and reinforced concrete top. Mineral wool provide for thermal insulation between levels if needed, acoustic resistance, and finally for the desired fire resistance, at least 120'. For a 120' fire resistance the performance of the slab range from 2;5 m span for a live load of 800 daN/m² to 7.5 m for a live load of 300 daN/m².

The profiled steel sheeting is the structural tensioned material. Special profiled forming are provided on both longitudinal edges to allows for a correct fitting and connection between two adjacent elements.

The mineral high density, 50 kg/m^3 mineral wool is a effective shuttering bed for the concreting of the top of the slab. This is a factory made product that allows for precise process and efficient product, ready to use on site.

Normal concrete C30 (fck = 30 N/mm²) is reinforced with RC bars welded on the steel sheeting. This welding provides point connexion between the tensioned steel and the compressed concrete creating a composite behaviour between the steel sheeting and the top concrete. The element resistance is more than the simple addition of the steel resistance and the resistance of concrete as it is in usual construction.

Depending of the live load to be used on the slab, the element can span from 3 meters for a live load of 880 daN/m² to 7 meters for a live load of 430 daN/m². More details are given in commercial papers and design tables form the producer.

Acoustic resistance is:

Rw (C, Ctr) = 58dB, Ln,w = 78 dB songle cofradal element and

Rw (C, Ctr) = 64dB, Ln,w = 66 dB with false ceiling

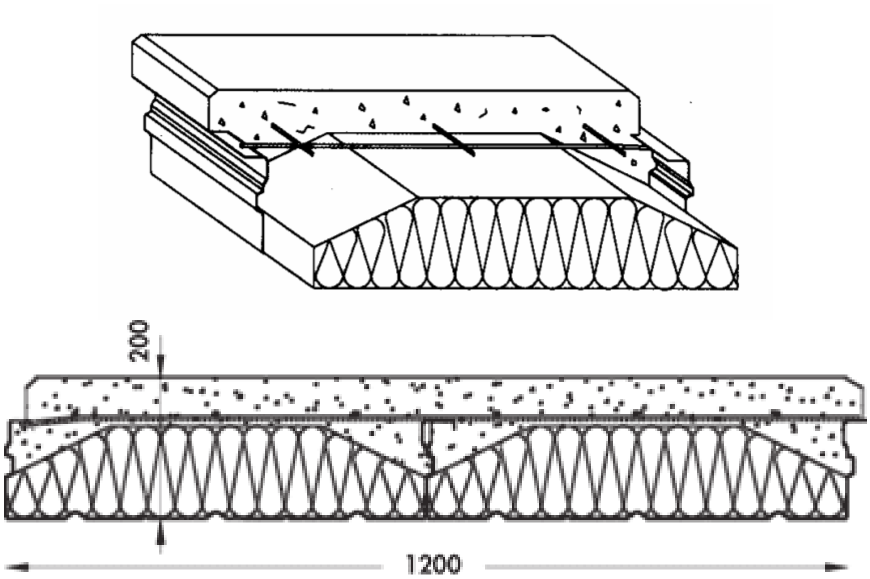


Figure 5.3 *3D view and section in a COFRADAL element*

Figure 5.4 *Delivering of COFRADAL on site. Fast and efficient arrangement on the lorry and transfer of a COFRADAL 200 element in a building refurbishing operation*

Figure 5.5 *Simple arrangement of the slab on the frame. Direct from the lorry to on the frame positioning*

Figure 5.6 *Top view of the slab before and after concreting of a light circulation surface*

Figure 5.7 *Under site view of the finished slab. False ceiling will be provided for services.*

5.2 National best practice in Germany

The office market has declined over the last two years. The total construction of new office space was approximately 3.42 million m² in 2004 compared to 4.2 million m² in 2003. But this trend is regionally seen very different.

5.2.1 HOESCH-ADDITIVE-FLOOR â

Description The HOESCH-ADDITIVE FLOOR® is a floor system which is commonly used in car parks, not only in Germany. It has recently also been used in multi-storey commercial buildings. The floor comprises of Hoesch steel sheetings with reinforcement and a concrete top course.

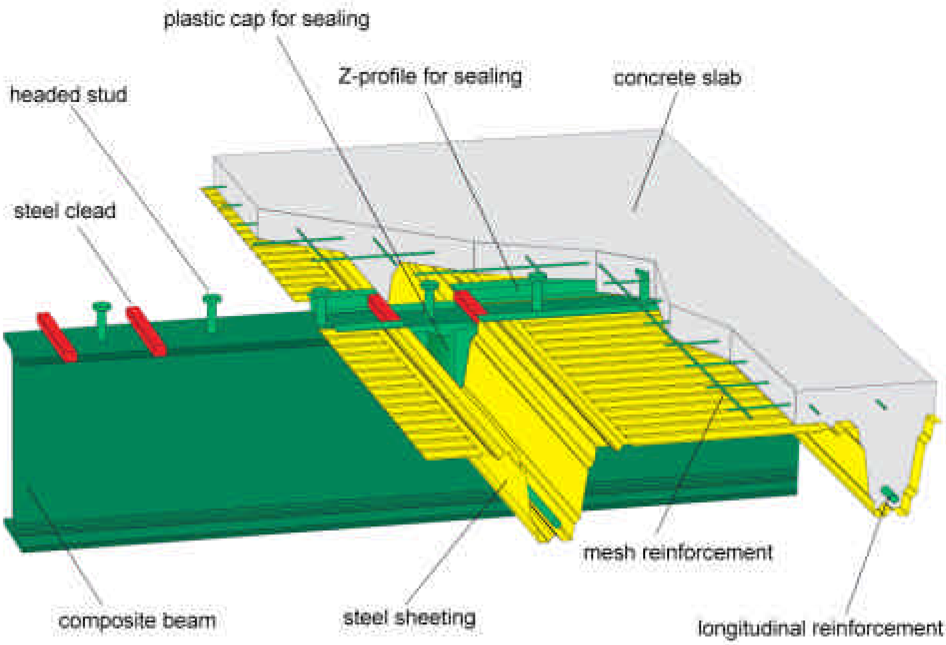
The steel sheeting is positioned between the flanges of the beams, so that the floor height is significantly reduced. The sheets are supported by special steel cleats welded onto the upper flange of the beams. Sheetings are fixed with fireshot fasteners onto the cleats.

As a primary support structure, any type of composite beam construction can be chosen, e.g. hot-rolled I-sections, cellular beams, etc., using primary and secondary beams or primary beams only. The concrete top course of the slab has to be co-ordinated with the required depth for composite action of the beams.

The steel sheeting and the concrete do not act as a composite slab. No shear connectors are provided between sheeting and concrete. The beam itself can be designed as a composite structure, therefore shear connectors are provided on the flange of the I-section like in Figure 5.1. The concrete slab acts as a ribbed floor with reduced self-weight compared to a massive slab. The slab spans between the beams, which leads to flexibility in arranging the studs on the beam flange.

In the construction stage the sheet acts as formwork to support the slab and other loads without propping for spans up to approx. 5.5m. The slab should not be propped during construction because of disadvantages in the ultimate limit state. If bigger spans have to be achieved, the slab should be concreted in two layers (ribs first, than slab). With that procedure the possible spans increase by up to 1.5m. Additionally the sheeting is able to act as a restraint against lateral torsional buckling of the beam.

For edge elements in the longitudinal direction, angles are mostly used also as formwork for concrete. Specially shaped components seal the construction during concreting. Sheetings are available in many different colours for individual soffits.



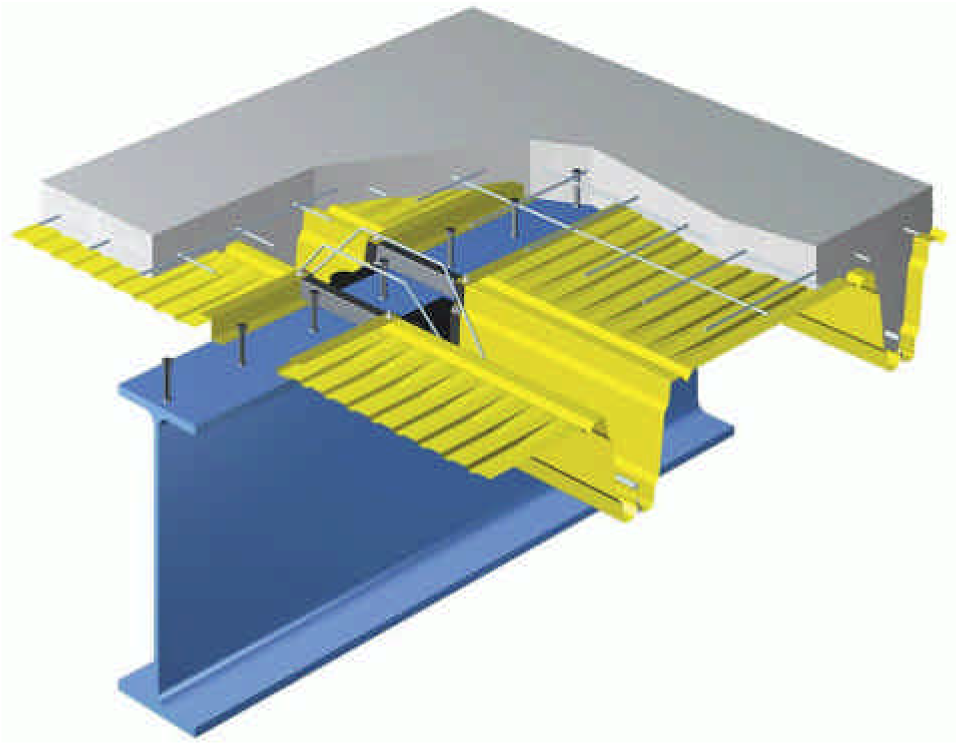


Figure 5.8 *Principle sketches of the HOESCH ADDITIVE FLOOR*^â

Main design considerations for the floor layout Decking requires propping for spans over 5.5 m, which leads to beam grids of 5.8m maximum. Slab depth is influenced by concrete cover to the deck (minimum 80 mm), depending on required depth for composite action with the beams. Slab grid is usually 750mm, i.e. the spacing between the ribs.

Advantages Slab spans up to 5.5m without propping in the construction stage.

Comparatively low self-weight of the rib-slab.

The slab does not disturb the composite action of the beams (studs can be arranged as needed).

Reduced floor height by lowering the steel sheets between the beams.

Steel sheets can provide restraints for beams against lateral torsional buckling at construction stage.

Fast construction of the sheets without the use of a crane.

Disadvantages Limited possibilities of service integration.

Fixing of services only possible with bolts onto the sheets or with anchors in concrete.

Services integration Unrestricted distribution of services below the floor. Small services can be passed in the ribs of the steel sheets and then through holes in the web of the beams (if provided).

Governing design criteria for beams Bending resistance will usually govern for S235 or S275 steel. Increasing the span leads to high strength steel e.g. S355 and S460, for which the deflection then usually governs.

Typical section sizes Depending on sections used for composite beams, see respective chapters above for more details.

Grade of steel Steel sheeting: S350 GD

Type of concrete Either normal weight concrete (NWC), 2400 kg/m3 dry density, or lightweight concrete (LWC), 1850 kg/m3 dry density, can be used.

Minimum C20 used for slab.

Overall floor zone Slab depth 205mm plus concrete cover (minimum 80mm, depending on the required depth for composite action of the beams). Overall floor zone depends on sections used for beams and services to be integrated (see respective chapters for detail information).

Fire protection For the slab up to R90 possible with additional rebars.

Connections The steel sheets are supported by special steel cleats welded onto the top flange of the beams for fast and easy construction.

Connections of beams depending on section used, in most cases simple (non-moment resisting) connections: double angle cleats, partial depth flexible endplates or fin-plates.

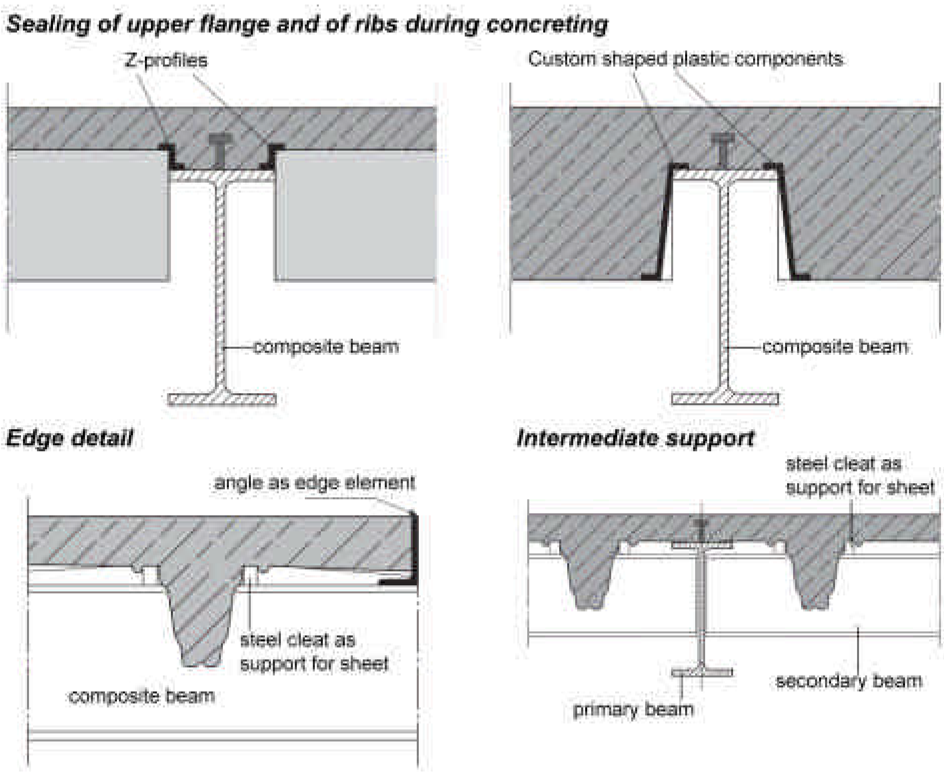


Figure 5.9 *Selected details of the HOESCH ADDITIVE FLOOR®*

5.3 National best practice in the Netherlands

5.3.1 The INFRA+ system

Description

The Dutch company PFL has developed a prefabricated concrete slab floor system with parallel-perforated support beams of steel and a (removable) top floor (hybrid construction). The system's objective is to separate the constructive elements from the services and offer increased flexibility in the design and functionality of buildings at reduced construction costs. The company searches a manufacturer of prefabricated concrete elements for manufacturing and/or contractors/licensees of turnkey projects.

The Infra+ floor system is a prefabricated concrete slab with parallel-perforated support beams of steel and a (removable) top floor (hybrid construction). One objective is to separate the constructive elements from the services (like sewage, water, telecommunication, data, ventilation etc.). It gives increased flexibility in design and functionality of buildings at reduced construction costs (10% for a reference office building, compared to traditional building methods as a result of a study carried out by the Dutch Association of Cost Engineers). The other objective is to create a dry building method (industrial building method) which improves scheduling of different disciplines and a more controllable building process. Because of having less weight (sometimes up to 50% compared to traditional housing), mounting and dismounting possibilities, extended lifetime of the components and changeability to new functions, Infra+ fits well to sustainable building principles.

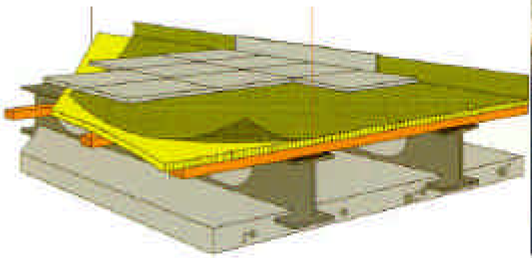


Figure 5.10 *INFRA+ system*

Typical beam span range

- Prefabricated Infra+ system span (act as secondary beams): 4.5 to 9.6 m
- Main beam span: 6 to 12m
- standard height according to maximum span: 275mm/4.50m, 295mm/5.40m, 355mm/7.20m, 445mm/9.60m.
- standard width of 2400 mm

Main design considerations for the floor layout

Hot-rolled steel beam connected by a concrete slab on the bottom –side

- Self-weight: From 1.60 kN/m^2 (excluding the cover materials)
- Vibration: measurements on existing building have shown that the minimum eigen-frequency is not less that 7 Hz.
- Acoustic properties: Noise insulation: The INFRA+ floor and the cover materials form a two-piece construction that, with the correct details, satisfies the requirements for offices and homes. *

- Noise absorption: The desired reverberation time depends on the project and can be achieved through various technical solutions.
- Since there is no ceiling, the concrete acquires a large accumulating capacity
- Ground level floors are available with insulation on the bottom, e.g. 80 mm EPS, Rc = 2.52 m2K/W. This includes the extra contact resistance produced by the two piece construction.
- Linear expansion coefficient according to the calculation factor, NEN 2880:12.10-6 [K-1].

Advantages Reduction of storey height; no false ceiling required; lighter foundation and support structure; less external wall surface and partition walls; lower installation costs;

Disadvantages Heavy elements with big dimensions

Services integration One of the main advantages of this type of floor is the flexibility because of the easy access to the services.

Governing design criteria for beams Deflection

Governing design criteria for decking/slab Deflection

Design approach Connection of main beams to columns

Infra+ system is put on the aupper beam flange as non-composite slab elements

Typical section sizes IPE 240-360

Grade of steel S235

Overall floor zone 250 to 370 mm

Grade of concrete Concrete specifications typically: C30

Fire protection Fire-resistance: Concrete floor: Non-flammable according to NEN 6064. The INFRA+ floor is fire resistant for a minimum of 90 minutes in accordance with the Bouwbesluit (Dutch Building Regulations).

Connections Simple (non-moment resisting) connections: double angle cleats, partial depth flexible endplates or fin-plates.

5.4 National best practice in Luxembourg

There has been a noticeable increase of composite steel-concrete office buildings during the last few years. These buildings are generally of 4 to 6 storeys and often there is a strong influence from architects concerning aesthetics e.g. the extensive use of glazing for the building envelopes (see Figure 5.11). There is a trend for the use of long span composite beams, spanning typically 15m to 18m, and a higher steel yield strength of S460 being used. Furthermore it is noticed that standard solutions are being adopted with typical beam and floor spans used for several buildings e.g. car parks and office buildings. Most of these buildings have underground car parks of 2 to 4 levels where fire safety is guaranteed through partially encased composite beams and columns. In the office levels, sprinklers are becoming more standard and with the modern fire design approaches, a lot of buildings can be built with reduced fire protection requirements or even without any protection to the structures. In the other cases partially encased beams and columns are widespread. Floor systems are usually made using prefabricated planks or steel sheets. Service integration is often dealt with by using cellular beams. In the case of long span composite beams, the pouring of concrete is often made in 2 or 3 phases in order to avoid propping of the beams.

Figure 5.11 *Office building- Chambre de Commerce- Luxembourg*

5.5 National best practice in the U.K.

The total construction of new office space in the UK is approximately 4 million m^2 per annum, approximately 50% being for speculative developers. However, most speculative buildings are 'pre-let' (to at least 50% occupancy).

The market share for steel is very strong in the commercial sector currently at 65%, and is even higher in central London. This is equivalent to over 250,000 tonnes of steel being used per annum.

UK flooring systems

All the flooring systems mentioned previously in Section 3 are commonly used in the UK. In addition two other types of flooring systems can be used which are more specific to the UK market. These flooring systems are:

- Slimdek
- Long span composite beams with web openings

5.5.1 Slimdek

Figure 5.12 *Service distribution below the floor in Slimdek*

Description Slimdek is a shallow floor system comprising asymmetric beams (ASB) supporting ribbed composite slabs using deep decking. ASB's are hot rolled steel beams with a wider bottom flange than top. The section has embossments rolled into the top flange and acts compositely with the concrete encasement without the need for additional shear connectors. The decking spans between the bottom flanges of the beams and acts as permanent formwork to support the slab and other loads during construction.

Span arrangements are normally based on a 6-9 m grid, with a slab depth of 280-350 mm. Decking requires propping during the construction stage for spans of more than 6 m. Reinforcing bars (16–25 mm dia) in the ribs of the slab give sufficient fire resistance.

A range of ASB sections is available in each of two serial sizes of 280 and 300 mm depth. Actual depths vary between 272 mm and 342 mm. Within this range, there are five ASBs with relatively thin webs and five ASB(FE) (fire-engineered) sections with relatively thick webs (equal to or thicker than the flanges). The ASB(FE) sections offer a fire resistance of 60 minutes without additional protection in this form of construction with normal office loading. All ASBs are rolled in S355 steel.

Services can be integrated by forming elongated openings in the webs of the beams, and by locating duct between the ribs of the decking, as illustrated in Figure 5.4.

Edge beams can be RHS *Slimflor* beams, which comprise a rectangular rolled hollow section (RHS) with a flange plate welded underneath, ASBs or downstand beams. Ties, normally Tees with the leg cast in the slab, are used to restrain the columns internally in the direction at right angles to the main beams.

Mesh reinforcement (A142 for 60 minutes fire resistance and A193 for 90 minutes) is placed in the slab over the ASB. If the top flange of the ASB is level with the surface of the concrete, the slabs each side of the ASB should be tied together to meet robustness requirements, normally by reinforcement (typically T12 bars @ 600 ctrs) passed through the web of the ASB. ASBs are normally designed as non-composite if the concrete cover over the top flange is less than 30 mm. (Note that a cover to the ASB of at least 30 mm is recommended as the reinforcement cannot be accommodated easily in less than 30 mm depth).

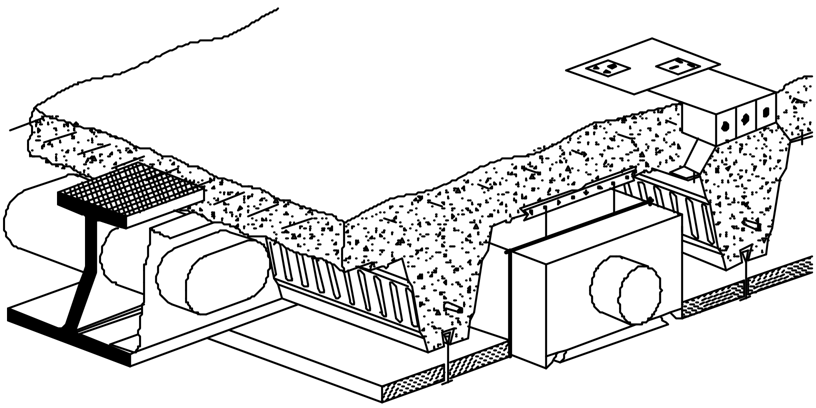


Figure 5.13 *Integration of services within Slimdek floors*

Typical beam span range

6–7.5 m grids, typically, although 9 × 9 m is possible.

Main design considerations for the floor layout

A central spine of ASBs with decking spanning onto edge beams will generally be more economic than a series of transverse ASBs, for buildings of rectangular plan shape. Torsion may govern beam design at a change in direction of floor span and for edge beams. RHS *Slimflor* beams resist torsional loading effectively.

Decking requires propping for spans over 6 m (propped twice at 9 m span).

Slab depth is influenced by the concrete cover to the deck (mainly for fire resistance), cover to the ASB (30 mm minimum), and cover to the edge beam. ASBs are designed as non-composite if the cover is less than 30 mm.

Detailing of connections around columns should be considered, as the ASB flanges are wider than the column and may need notching.

Slimdek flooring can be designed using the *Slimdek* suite of software (ASB, Comdek and RHS). Further information is available at www.steel-sci.org.

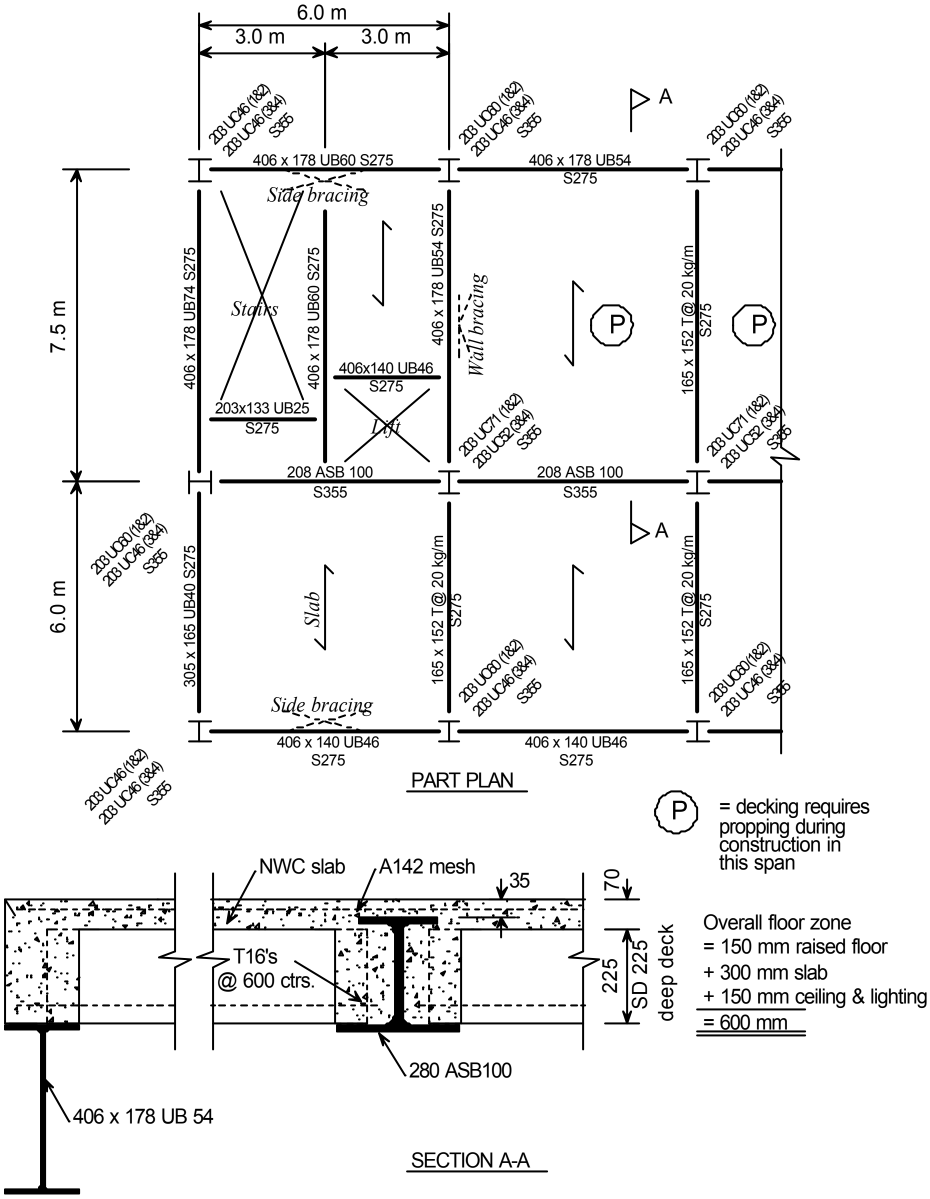


Figure 5.14 *Slimdek – floor steelwork arrangement for a four-storey rectangular building (central spine ASB and downstand edge beams)*

Advantages Shallow floor zone – leading to a reduction in overall building height and cladding costs. The virtually flat soffit facilitates service installation and offers flexibility of internal wall positions.

Disadvantages The steel weight is often heavier than in other floor systems.

Connections require careful detailing due to the width of the bottom flange.

Services integration Unrestricted distribution of services below the floor. Small services and ducts (up to 160 mm dia) can be passed through holes in the beam webs and between ribs in the decking.

Governing design criteria Slab depth may be controlled by fire resistance or concrete cover to the ASB/edge beams

Deflections, fire resistance, torsional loading governs the size of ASBs.

Design approach

1. Assume beams on a 6 m, 7.5 m or 9 m grid. (Note that decking spans over 6 m requires temporary propping, which may affect the construction programme.)

2. Choose the decking and design the slab. Assume C35 concrete, with propping if required. Ensure chosen slab depth and reinforcement meet the fire resistance required.

3. Design the ASBs using software. Choose fire engineered sections if fire protection is to be avoided. Ensure that the depth of slab covers the ASB by at least 30mm, or choose a slab depth to be flush with the top of ASB, and provide reinforcing bars through the beam web.

4. Design edge beams using RHS *Slimflor* beams or downstand beams, where cladding details permit. Ensure the edge beam depth is compatible with the slab depth.

Typical section sizes

280 ASB 100 for 6 m span at 6 m centres

280 ASB 124 for 7.5 m span at 7.5 m centres

300 ASB 249 for 9 m span at 9 m centres.

Grade of steel

ASBs are only available in S355 steel.

RHS *Slimflor* beams are available in S275 and S355.

Type of concrete

Either normal weight concrete (NWC), 2350 kg/m^3 dry density, or lightweight concrete (LWC), 1850 kg/m^3 dry density, can be used.

Overall floor zone

1000 – 1200 mm with air conditioning (and raised floor) see figure 5.7

700 – 900 mm with light services (with raised floor) – see figure 5.8

Fire protection

Fire engineered ASBs with the web and top flange encased with concrete do require additional fire protection for up to 60 minutes.

Thin web ASBs require fire protection for greater than 30 minutes - normally by board to the bottom flange.

RHS *Slimflor* edge beams normally require fire protection for greater than 60 minutes. - normally by board.

Connections

ASBs require end plate connections (typically, 6 or 8 bolt) to resist torsional loads. RHS *Slimflor* beams often use extended end plate connections to minimise the connection width.

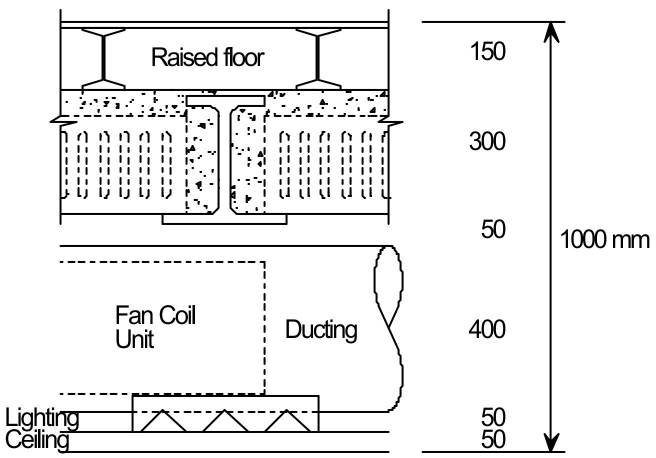


Figure 5.15 *Slimflor - Typical cross-section with air conditioning*

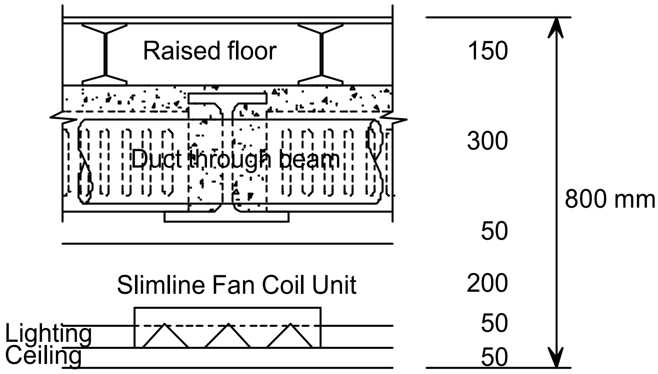


Figure 5.16 *Slimflor - Typical cross-section without air conditioning*

Long span composite beams with web openings

Description This system consists of composite beams using rolled steel or fabricated sections supporting a composite slab in a long-span arrangement of, typically, 10 to 18 m. Grids are either arranged with long-span secondary beams at 3 m to 4 m spacing supporting the slab, supported by short-span primary beams, or with short-span secondary beams (6-9 m span) supported by long-span primary beams. The depth of the long-span beams means that service openings, if required, are provided within the web of the beam. Openings can be circular, elongated or rectangular in shape, and can be up to 70% of the beam depth. Web stiffeners may be required around large openings.

Figure 5.17 *Fabricated beam with off-site fire protection*

Typical beam span range Long-span secondary beams: 9 m to 15 m span at 3 to 4 m spacing.

Long-span primary beams: 9 m to 15 m span at 6 to 9 m spacing.

Main design considerations for the floor layout

Secondary beams should be placed close enough to avoid propping the decking (3 – 4 m).

Large (elongated or rectangular) openings should be located in areas of low shear, e.g. in middle third of the span for uniformly loaded beams.

Advantages

Large column-free areas.

Reduction of the overall floor height and consequently of the buildings height

Disadvantages

Services integration

Service ducts pass through openings in the web of the beams

Larger service units and ducts can be situated between beams.

Governing design criteria for beams

Critical checks are usually deflections and dynamic response.

Governing design criteria for decking/slab

Deflection of the decking in the construction condition.

Fire resistance (affects the concrete cover to the decking and mesh reinforcement size).

Design approach

1. Use long-span secondary beams at 3 – 4 m spacing, on a 6 m, 7.5 m or 9 m column grid, or long span primary beams for fabricated sections.

2. Choose the decking and slab, using decking manufacturer's load tables or software. Ensure the chosen slab and reinforcement meet the fire resistance required.

3. Design beams using software. Use studs placed in every steel sheeting rib on secondary and at 150 mm spacing on primary beams. Note the orientation of the decking will differ between secondary and primary beams. Ensure any openings in the web are of a size and location agreed with the services engineer, and allow for insulation around the services.

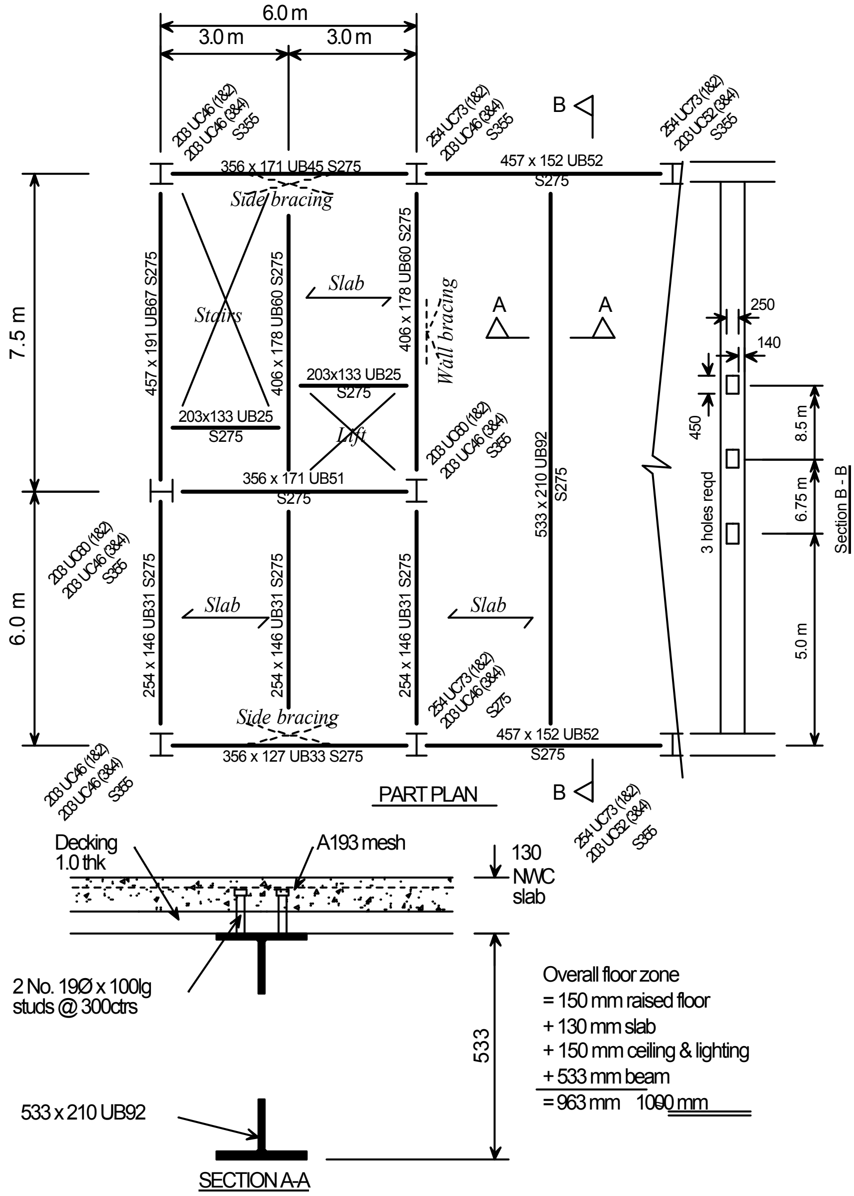


Figure 5.18 *Long-span composite beams (with web openings)*

Typical section sizes Depth of beam ≈ span/17-20.

Grade of steel S275 for beams controlled by deflection or S355 for highly perforated beams.

Type of concrete Either normal weight concrete (NWC), 2400 kg/m^3 dry density, or lightweight concrete (LWC), 1850 kg/m^3 dry density, can be used.

Overall floor zone 1000 mm for 13.5 m span (with 350 mm deep web openings)

1050 mm for 15.0 m span (with 400 mm deep web openings)

Fire protection Board, or intumescent coating (Intumescent coatings can be applied off-site as a single coating up to 1.8 mm to achieve 90 minutes fire resistance).

Connections End plate connections, resisting shear only.