

Construction Technology 3

Steel Frame and Composite Design

TECHNICAL

Learning Outcomes

Aim

- To provide designers with guidance on the prime factors to be considered, the options available and the implications of a given choice of structure.

Composite Construction

● **Reasons for using composite construction:**

- Economic with faster erection facilitating earlier completion.
- Reduces interest charges and advances rental income.
- Twice the strength of the equivalent non-composite beam in conventional steelwork, but up to 4 times stiffer.
- Shallower structural depths, low storey heights with savings in cladding costs
- or more space for services within the same overall floor to floor height

Composite Construction

- Although comparative design demonstrates that savings in steel weight relative to non-composite construction can be 30 to 50 per cent
- these savings do not necessarily translate directly into overall cost savings because of the need for shear connectors, which are necessary to develop the composite action between the steel and concrete.
- Savings in the overall cost of the superstructure (beams, slabs, columns) of a typical building can be 15-20 per cent, not including the savings on the cost of the external and internal fabric if the shallower storey heights are achieved.

Grid Size

- The choice of grid size (column spacing) is important because although steel is popular due to its ability to span further than simple reinforced concrete for the same structural depth, costs per sq m rise as the column spacing increases.
- However, these additional costs may be small in comparison with the economic and functional benefits realised from greater areas of uninterrupted useable floor space.
- Internal columns are very unwelcome in high-rise schemes, for example, as they become so large in plan area due to high loading.
- Column grids for many office developments are in the 6-9 m range with a 1.5m common module space planning
- longer spans, particularly in steel can be achieved for only a modest premium, 2 to 3 per cent of the overall building cost.
- A 9 m grid is more common today.
- Users and developers are constantly demanding more column-free space and 12-18 m spans are becoming increasingly popular. Agents are finding column-free spaces easier to let, especially in the current market; they may well command a premium.

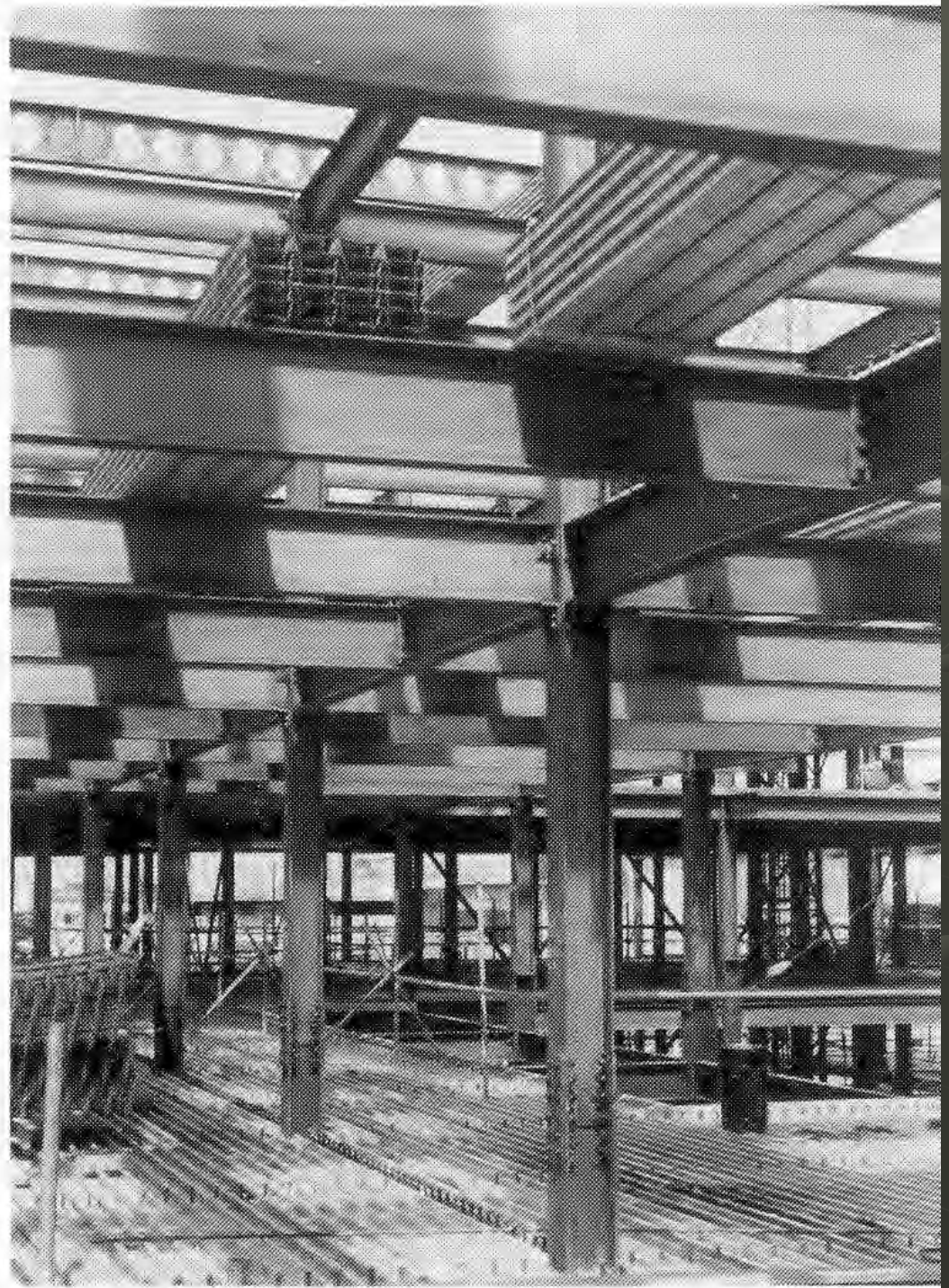
Composite Beams

- Composite beams behave essentially like a series of T-beams in which the concrete slab acts as the compression flange and the downstand steel section acts as the tension resisting element.
- The structural connection between the two materials is made by shear connectors. Composite action serves to increase both the strength and stiffness of the steel section, permitting it to span further or support heavier loads.
- The overall structural depth not only includes the steel section but also the composite slab. For efficient design of composite beams it is often found that the ratio of span to overall structural depth is in the range of 1:18-20. (Reinforced concrete beams have a 1:15 -18)

Composite Decking

- This is a profiled steel product, like roof sheeting, but with embossments or other mechanical means of improving the connection between the decking and the concrete placed on top of it.
- Slab depths of 120-150 mm are common today.
- Current practice is to design for the longest spans which can be achieved without the need for temporary propping; a 3 -3.5 m deck span appears to be the most popular.
- Many deck profiles are available but generally they are of two broad types - the dovetail and the trapezoidal. A 50 mm deep profile can usually support loads over a 3 m span.
- The embossments or indentations in the profile are intended to improve the shear bond behaviour of the composite slabs. There is no particular significance to the shape of these embossments provided they are deep enough to reduce the slip between the concrete and the decking by a mechanism known as 'mechanical interlock'.

Composite construction in the making. Decking sheets stack much more compactly than formwork and are usually used short enough to avoid propping when concrete is poured.



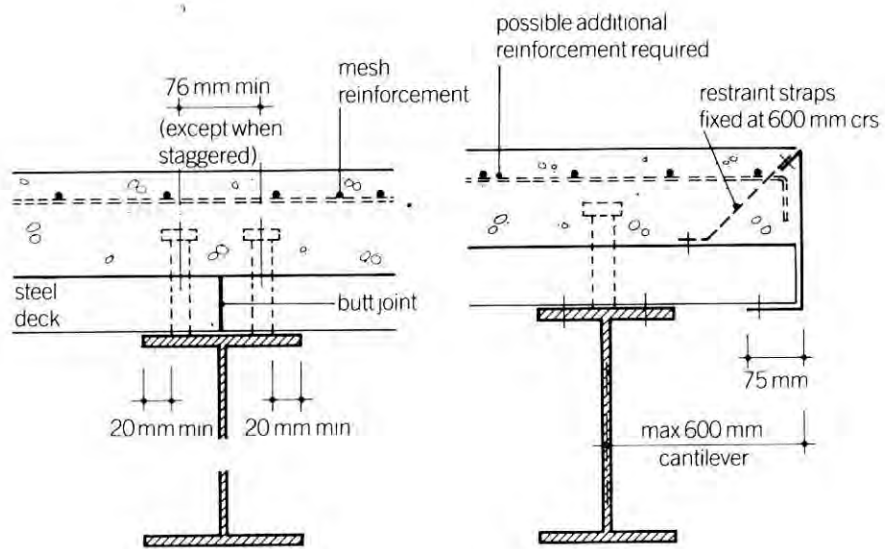
Composite Decking

- Composite decking is usually laid as long sheets up to 12 m long and is fastened down at every beam.
- In this way it offers a number of advantages:
- **it** supports loads during construction
- **it** stabilises the structural members and stiffens the frame against wind loads
- **it** provides a safe working platform
- **it** acts as a safety net against falling objects from above
- **it** acts as transverse reinforcement to the composite beams virtually eliminating the need for large amounts of reinforcement bars
- **it** distributes shrinkage strains, preventing serious cracking of the concrete
- **it** develops composite action with the concrete to resist the imposed loading.
- This form of construction ensures it is quick and easy to erect.
- Large bundles of decking can be lifted into place with limited subsequent use of crane facilities. The extent of crane use often determines the critical path, so as crane use reduces so does the overall erection programme.
- Decking out normally occurs shortly after the main steel members have been erected. Concreting is done one or two floors behind, after shear connectors, mesh reinforcement and edge trims have been positioned.
- Overall there are fewer elements on the critical path. This construction method is not very sensitive to the weather.

Shear Connectors

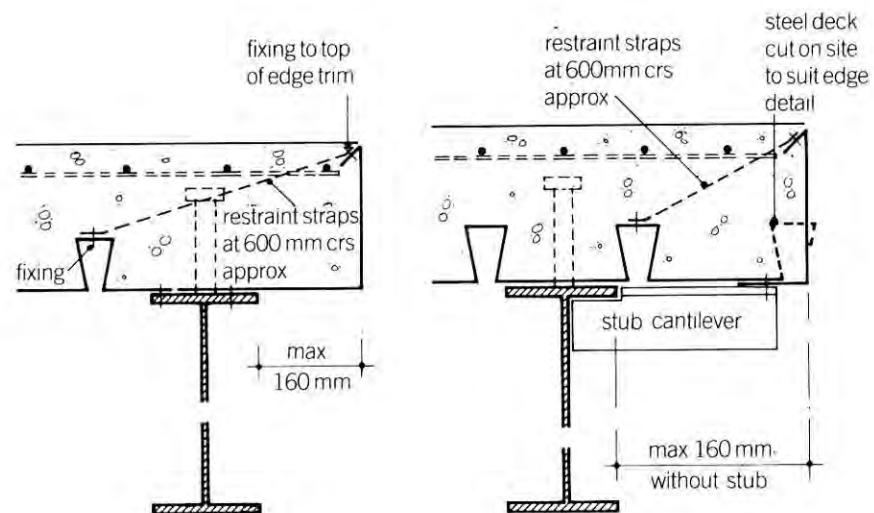
● Shear connectors

- Shear connectors are usually 19 mm in diameter, 100 mm long studs with a formed head and are individually welded through the steel decking to the steel flange by a hand-operated welding gun.
- Each weld takes about two to three seconds. The gun requires a 415 V 3-phase supply or a mobile generator. This on-site process cannot be used for painted beams and is not recommended for use in freezing conditions. In such circumstances the prewelding of studs may be appropriate.
- Alternatively a shot-fired connector could be used. This has the advantage of not requiring site power and can be used with painted beams.
- The shear strength of a 19 mm diameter welded stud can be up to 10 tonnes compared to 3.5 tonnes for a shot-fired connector, 4a-d, 5.



a

b



c

d



Types of Concrete

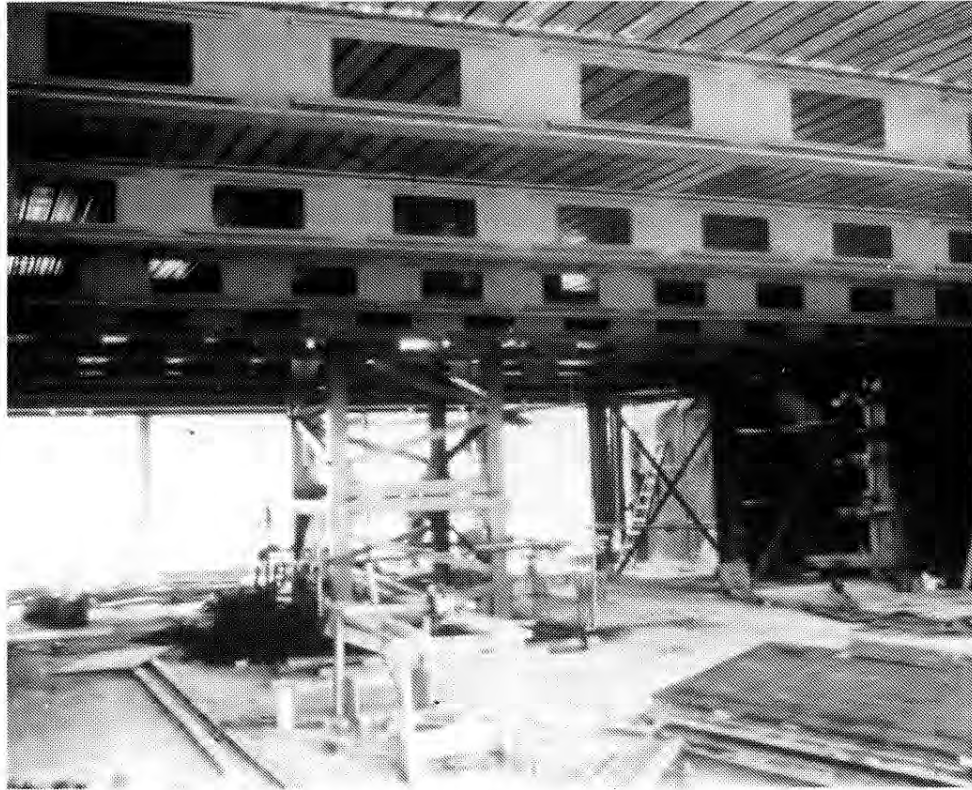
- Two types of concrete are used in the UK, a lightweight aggregate concrete or the more usual heavier version.
- The compressive strengths are typically 30 to 40 N /mm . Both can be pumped into place, with the lightweight concrete being easier to work because of its rounded aggregate. Although the lightweight mix is about 10 per cent more expensive, this is more than offset by the savings resulting from the weight reduction of the floor.
- However, suppliers of ready-mixed concrete are sometimes reluctant to store the more expensive lightweight aggregate unless they are convinced they will enjoy a large and regular demand.

Long-span alternatives

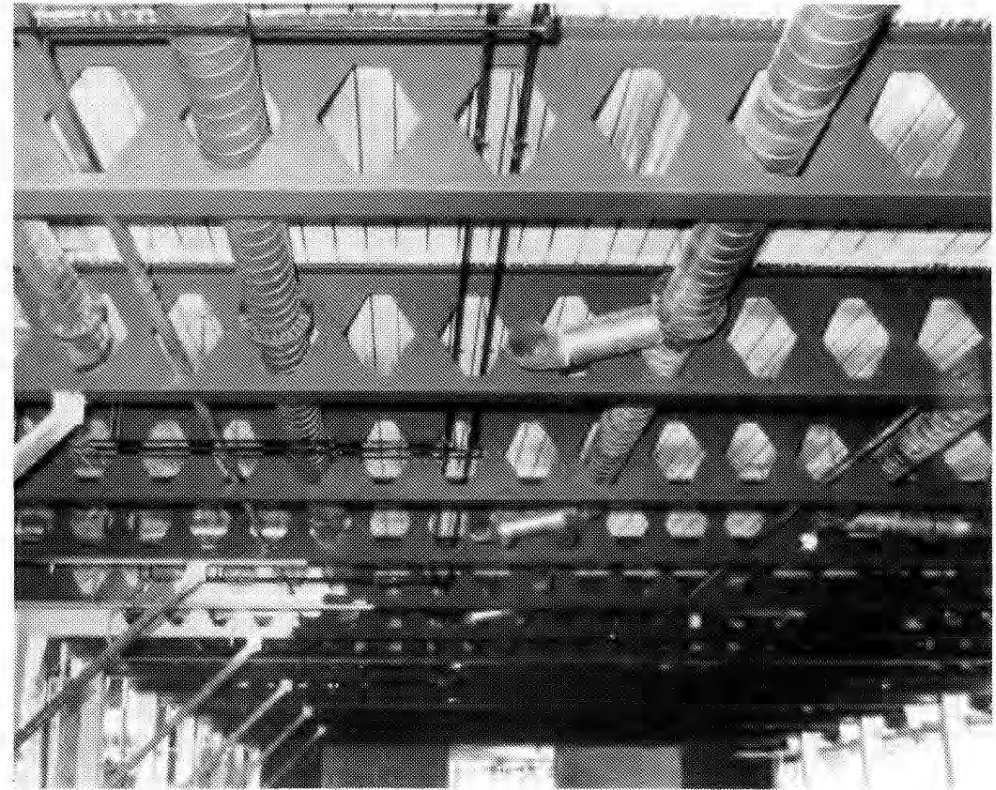
- One of the principal advantages of steel over concrete is its ability to span further with less material.
- Fabricated tapered girders, haunched beams, parallel beam systems, composite trusses, stub girders and castellated beams may all be viable.
- The optimum solution depends on:
 - spans of primary and secondary beams
 - span/depth ratio
 - necessity to contribute to sway resistance
 - cross-sectional area of service ducts
 - location of major ducts across span, including consideration of general distribution routes and crossover positions
 - looseness of fit between services and structure, especially important for shell and core developments where particular tenants may require additional servicing.
- As spans increase so does the depth of structure. To avoid increasing the floor-to-floor depth to accommodate the integration of services, there are a number of solutions which incorporate these services within the overall structural zone.
- It is now almost inevitable that building services will change significantly during the life of a commercial building whereas the structure will not and the designer should take this fundamental principle into account when determining structural solutions.

Openings in webs of composite beams

- This is appropriate for lightly serviced buildings, and is one of the most commonly used methods of incorporating services within the structural zone.
- Up to 70 per cent of the depth of the beam can be safely used provided that openings are located towards the centre of the span.
- The advantage of this system is that modest-sized openings can be formed where they are needed.
- The composite action around openings means that the loss of strength of the beam due to web openings is often not significant.



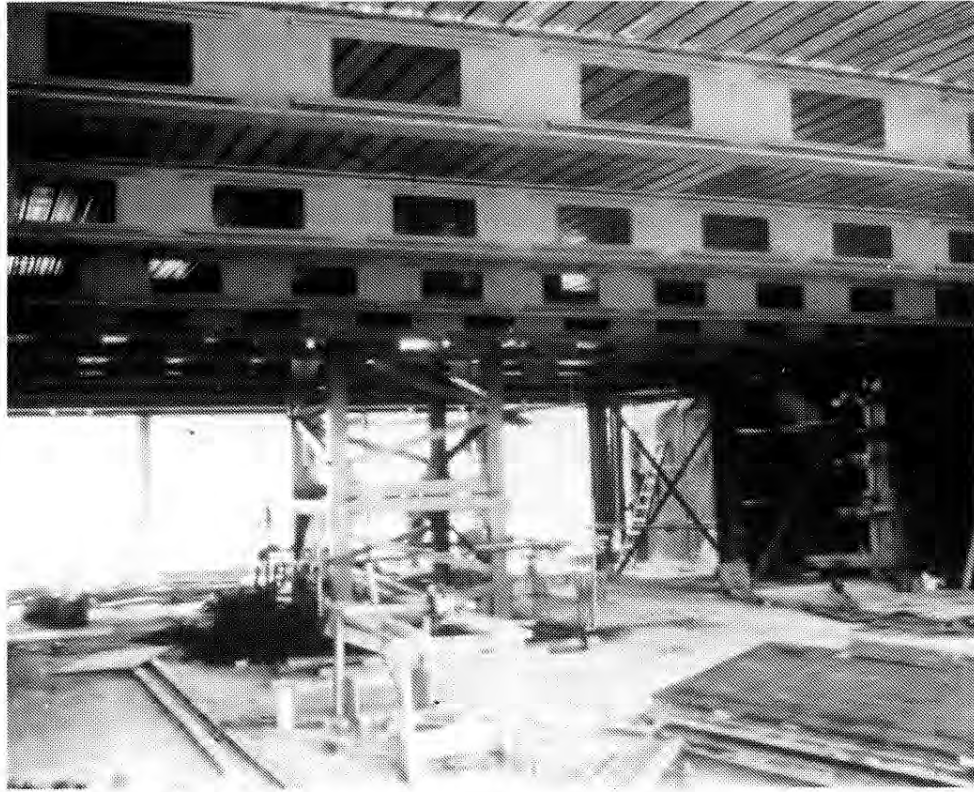
Larger web openings more appropriate for running modest servicing flexibly.



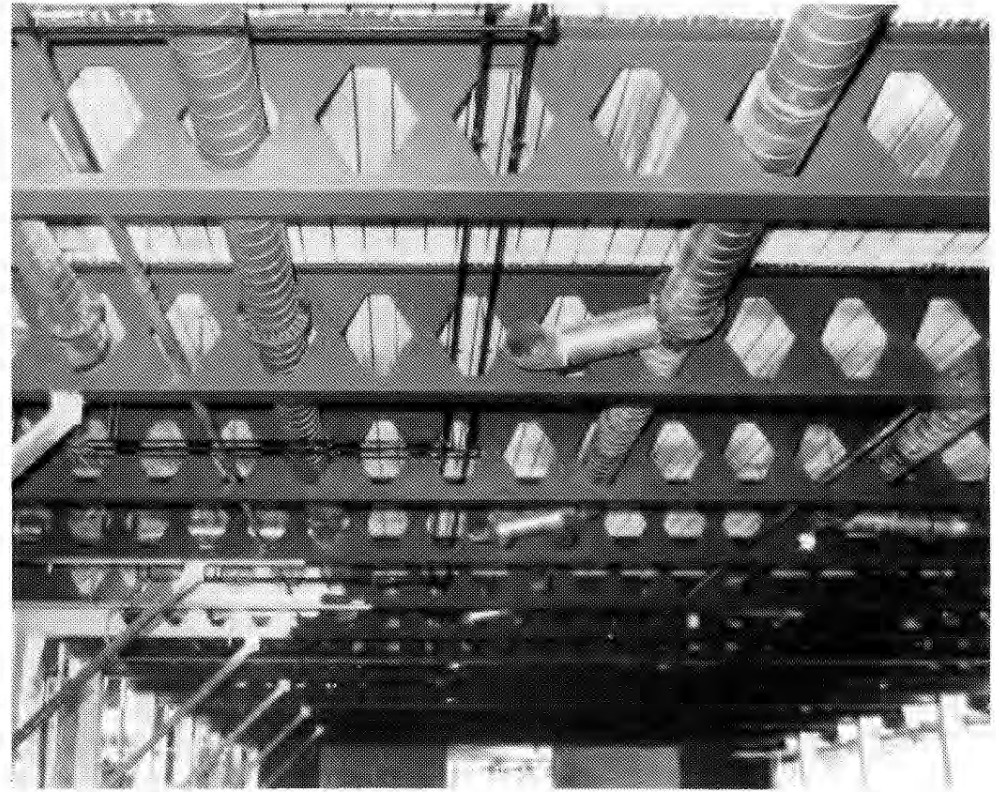
Castellated beams — long spans with light loads and light servicing.

Castellated beams

- Castellated beams have been used as secondary beams in some buildings, but they suffer from low shear resistance and cannot readily resist heavy point loads.
- They have primarily been used as long-span roof beams where their attractive shape is often expressed architecturally.
- With only light loading they can readily span 15 m without intermediate supports.



Larger web openings more appropriate for running modest servicing flexibly.

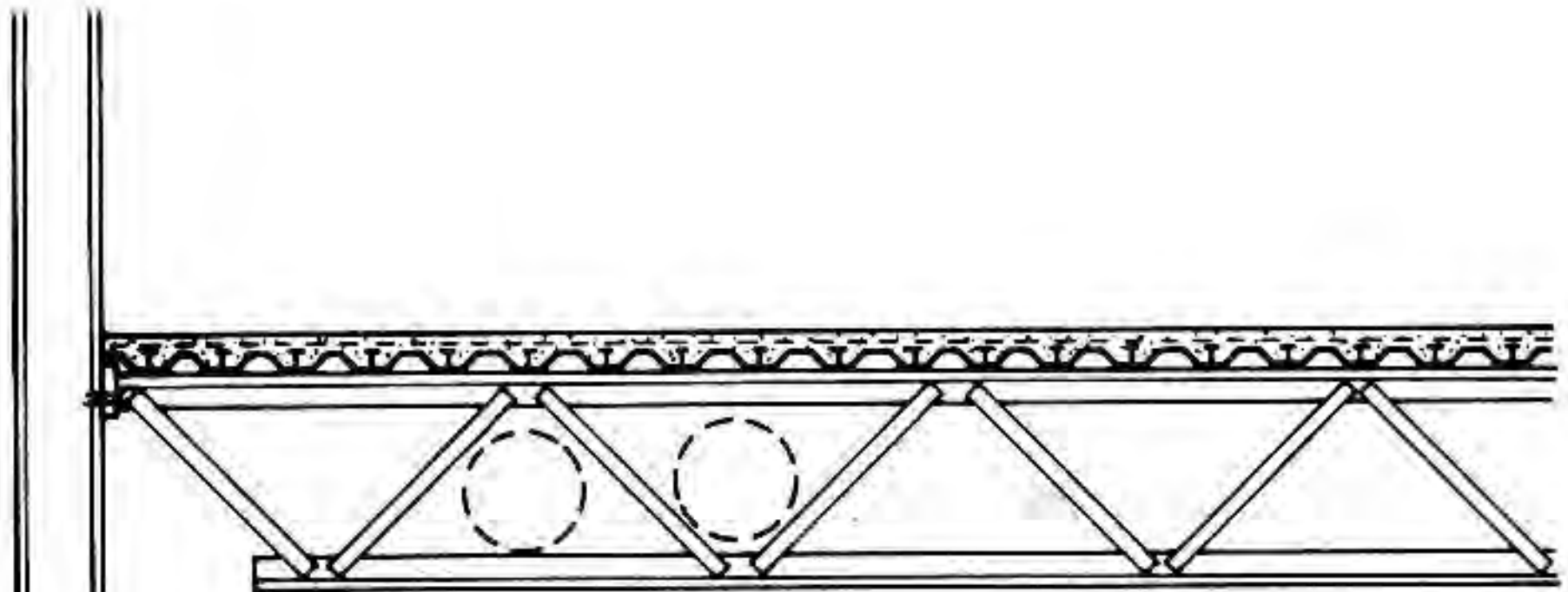


Castellated beams — long spans with light loads and light servicing.

Composite trusses

- **Composite trusses**

- The benefits of composite action in this instance lead to a reduction in the size of the top chord and permit offset of the bracing member from its regular position where this would, say, interfere with a services route.
- It is also possible to provide a greater zone for services by omitting bracing members at mid span.
- The main disadvantage of the truss is the expense of fabrication and additional fire protection. Composite trusses are only likely to be the preferred solution for spans in excess of 12m, 15, 16



Composite truss with service routes in principle

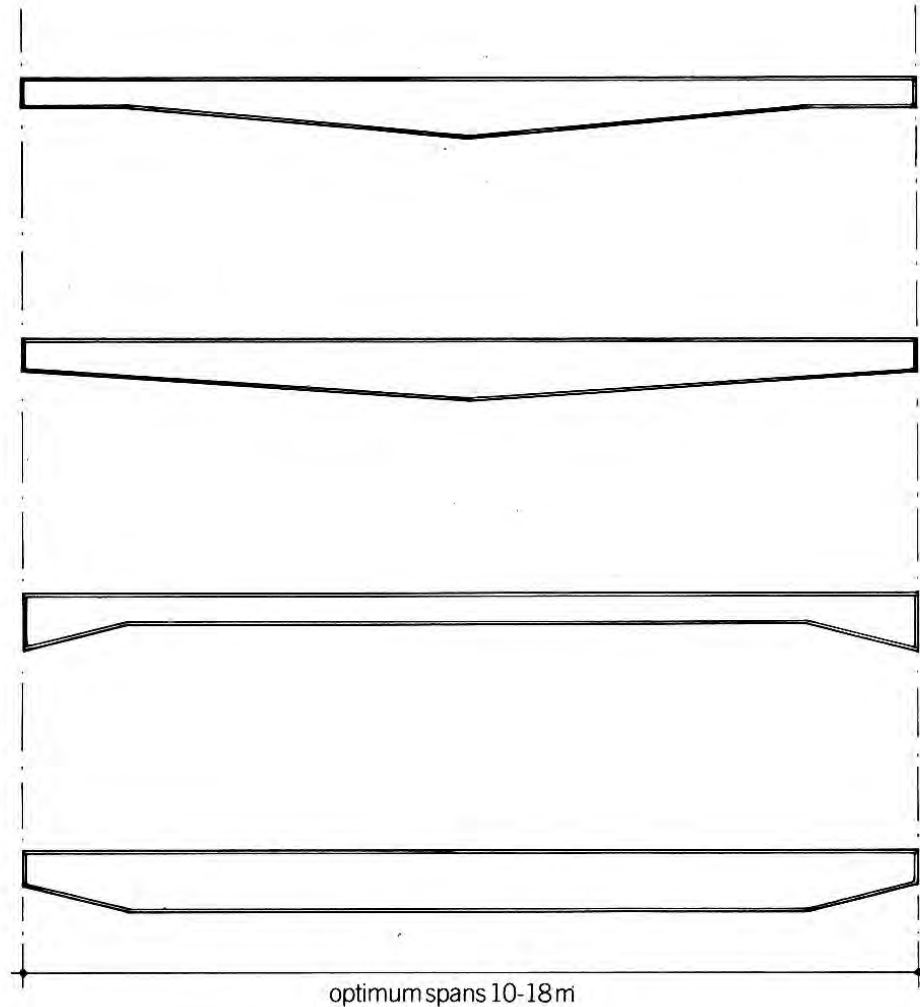


Composite truss

Tapered beams

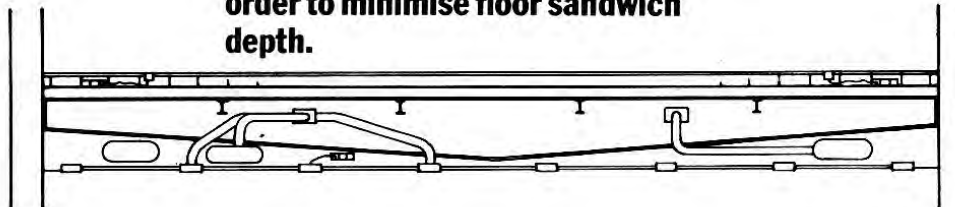
- **Tapered beams**
- Fabricated sections are most likely to be economic for spans above 12 m. These are fabricated from steel plates rather than standard sections.
- The taper of the bottom flange is usually 5 to 6° - such that the beam depth is reduced by half at the supports relative to mid span.
- Services are located in the triangular voids adjacent to the columns.





optimum spans 10-18m

**Typical tapered beam profiles
(Ward Structures) and bottom, an
example of running larger services
where the beam is shallower in
order to minimise floor sandwich
depth.**

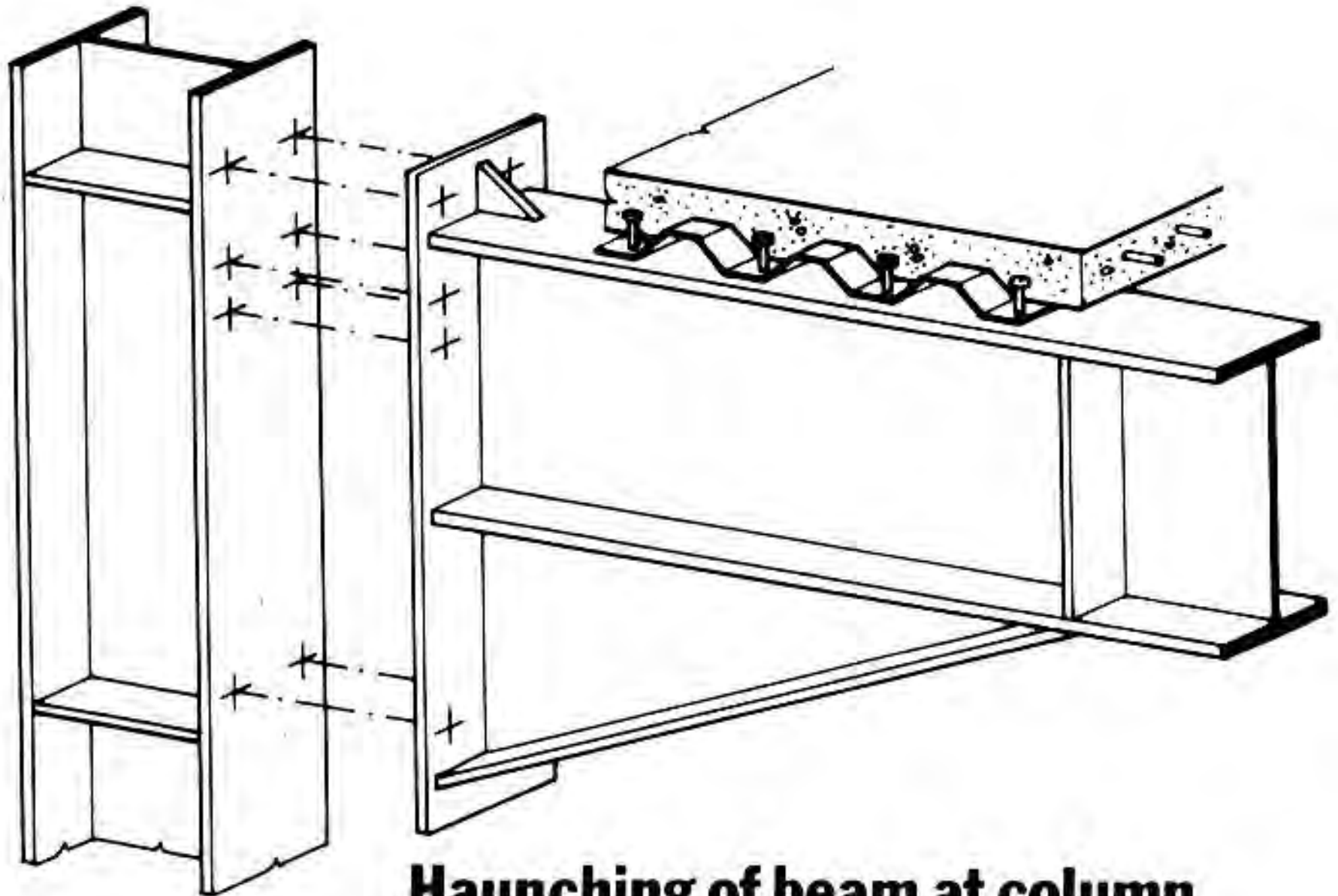


Haunched beams

- **Haunched beams**
- In this system the beams are stiffened at the connection with the column, thus minimising the structural depth and allowing the services to pass underneath the beams.
- The main beams are usually too shallow for holes to be formed in the web.
- Unfortunately the column size increases significantly and there may be difficulties in arranging service around the haunching.
- Sometimes it is difficult to achieve continuity at the corners of the building.



Haunching of beam at column

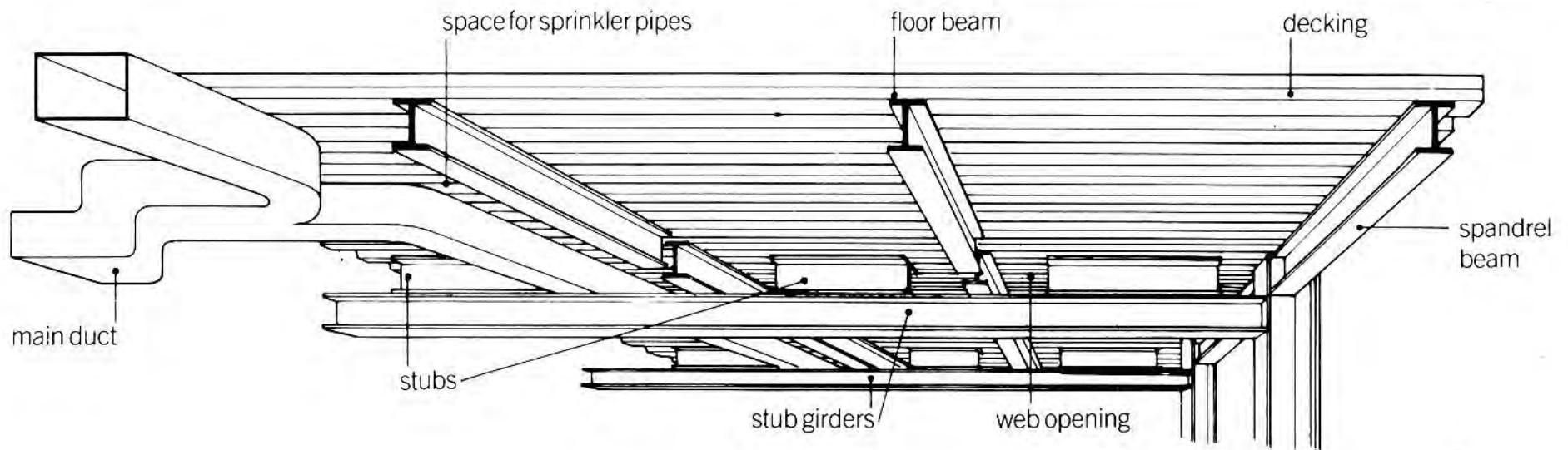


Haunching of beam at column

Stub girders

- **Stub girders**

- In this system, tension is resisted by the bottom chord (usually a steel column section) and compression resisted by the slab.
- Shear is transferred by stubs on the bottom chord and the slab openings are located adjacent to the stubs.
- Secondary beams are designed as continuous beams spanning over the bottom chord.
- Stub girders are most efficient in the 12-15 m span range, but they have been designed up to 27 m span.



Stub girder floor in principle with stubs leaving space for secondary beams and services distribution.