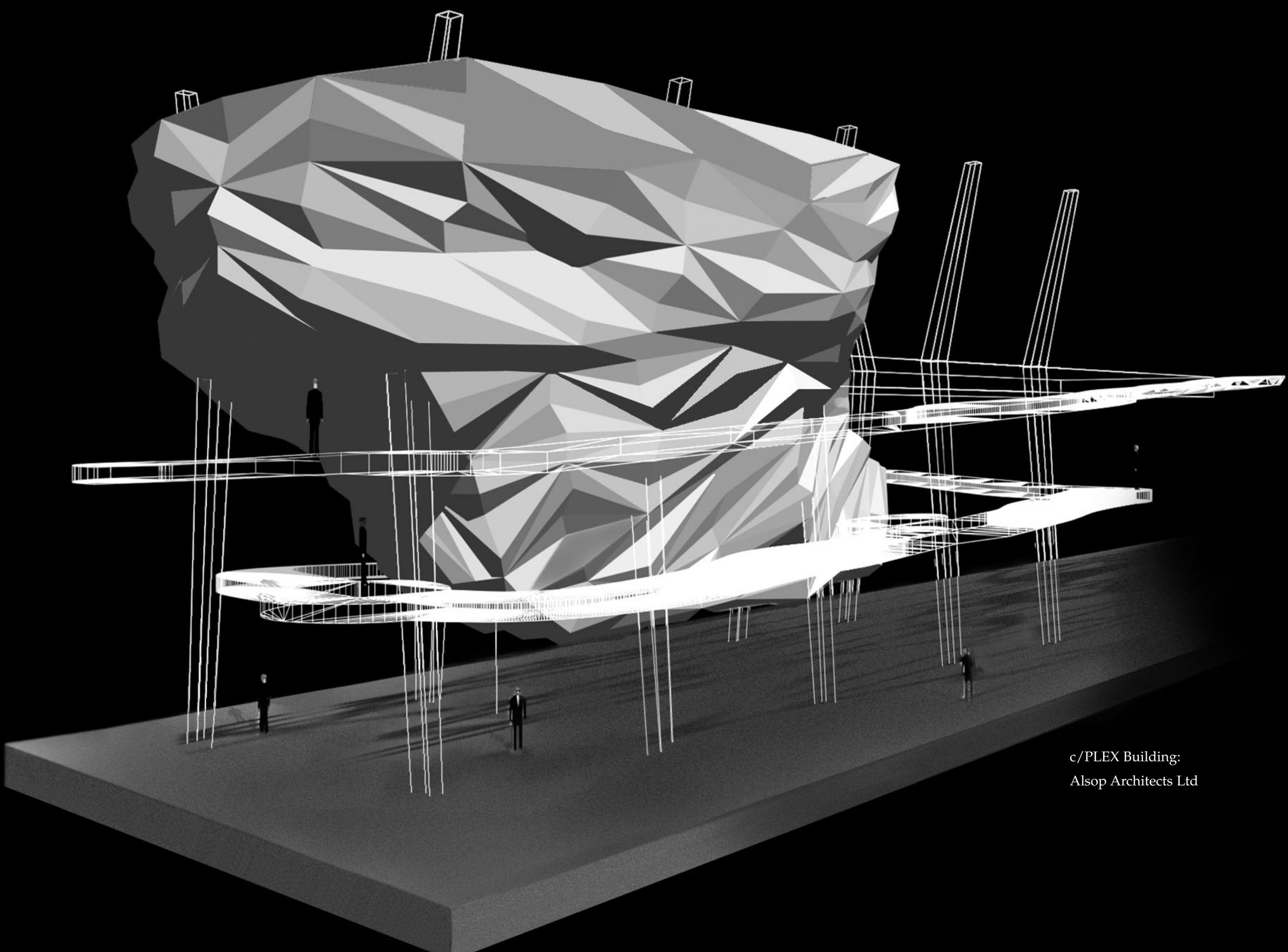
Architectual Teaching Resource

STUDIO GUIDE

Second Edition



c/PLEX Building:
Alsop Architects Ltd

The Steel Construction Institute

corus

FOREWORD

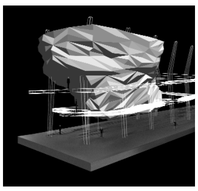
This Studio Guide, which is also available in an electronic format, provides an overview of common structural steelwork solutions and complements the *British Steel Architectural Teaching Programme* distributed to all Schools of Architecture in the UK in 1996.

The Architectural Teaching Programme comprises 36 lectures, over 1000 slides, videos and computer programmes, and provides a comprehensive review of the architectural aspects of structural steelwork.

It is intended as an educational resource for architectural and engineering students and is a simple reference for use in practice.

General structural design information is presented in good faith, but is intended only as a guide for student projects. Full structural calculations should be used in relation to building projects.

The Studio Guide was written by Professor Raymond Ogden (SCI Professor in Architectural Technology at Oxford Brookes University), with contributions from Professor Roger Plank of Sheffield University, and Dr Mark Lawson and James Atree of the SCI.



Front Cover:
c/PLEX, West Bromwich

c/PLEX represents a radical gesture for community architecture, born from the conviction that architecture can be a catalyst for regeneration and renewal. The client, Jubilee Arts, has long being a champion of the cause – using arts as a source of community renewal and social and economic regeneration.

The cover picture shows the 'Sock', a large sculptural element within the external envelope of the building. The 'Sock' contains three floor levels, which are linked by a snaking ramp. The 'Sock' has a structural steel frame with composite concrete floors constructed using steel decking.

Scheduled for completion in 2005, c/PLEX represents both a starting point and an opportunity for the people of West Bromwich, improving the town's eroded sense of identity.

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The Steel Construction Institute

The Steel Construction Institute is an independent, membership based organisation which was founded in 1986 to develop and promote the effective use of steel in construction. Having developed a highly valued framework for engineers, it is now involved in a number of research programmes focused on architectural issues including environmental projects.

For membership details (including student membership) and further information on publications and courses, please contact the Membership Manager.

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www.steelbiz.org – the 24 x 7 online technical information system for steel design and construction.

corus

Corus Construction Centre

Corus Construction Centre is an information source for designers and users of steel in the construction business. It provides a fast, efficient, 'one-stop' technical support service across all construction and construction-related products and applications. It can be contacted on a single hotline number, 01724 40 50 60.

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Lowry Centre, Manchester

Alsop Architects Ltd

Peckham Library

Nicolas Grimshaw

National Space Centre

Wilkinson Eyre (Nick Wood)

Gateshead Millennium Bridge

INTRODUCTION

Steel is synonymous with modern architecture. Throughout the twentieth century the material has inspired architects and engineers, for it combines strength and efficiency with unparalleled opportunities for sculptural expression. Today, in an era of architectural pluralism, and of engineering innovation, steel plays a central role in many of the most sophisticated and accomplished examples of modern building design. Partly this is due to the strides that have been made in metallurgy, structural analysis, fabrication and construction; but perhaps more fundamentally it is testament to the continuing commitment and fascination of architects and engineers with a material that offers outstanding design opportunities.

The key attribute of steel is its high strength to weight ratio, which gives remarkable spanning and load carrying ability. Steel lends itself to prefabrication. Whole structures can be created in a factory environment and then constructed quickly on site. Steel buildings are highly adaptable, in that frames can be modified and altered. Costs are low, recycling simple and aesthetic opportunities rich and varied. As designers, fabricators and constructors continually advance the boundaries of steel design, both technically and expressively, the role as a core part of modern architecture seems assured.

Steel is basically iron and carbon, but its properties can be enhanced and modified by the addition of other alloying elements and by the manufacturing process. The material is then made into sections, plate, or sheet, and these simple products used to produce structures and building components.

Standard approaches have evolved for many types of structure, the most common of which are described in the following Sections. They are not constraining however. Departures from norms are commonplace, for steel lends itself to creative solutions. Modern architecture is rich with solutions that defy simple categorisation.

The most widely used structural frames rely on hot rolled steel sections; the material has been heated and passed as a billet through heavy rollers that gradually reduce the cross-section whilst at the same time increasing length; the material flows to the required shape. Simple wide span column and beam frames where the structural members are arranged in a three dimensional matrix like the solutions on pages 8, and portal frames such as that on page 9 are mainly based on these sections.

For larger spans, hot rolled sections and plate can be fabricated to form particularly deep beams or other structural members such as those shown on page 11, and the same technique can be used for geometrically complex members such as the roof beams on the Renault Centre or the steel arch of Lehrter Bahnhof. Standard sections can also be curved after manufacture using heavy bending equipment, or be converted to perforated web profiles using a variety of approaches, some of which split the beam into two and then reweld it so that its depth and spanning ability is much increased.

Steel Arch, Lehrter Bahnhof, Berlin

Von Gerkan Mary Architects

Lighter steel sections can be formed by bending sheet steel to C or Z sections. Normally this is done using either a press or folding machine for special sections, or a cold rolling line for standard sections. Cold formed light steel sections generally have greater structural capacity than equivalent timber sections, with common structural profiles ranging from around 75 to 500 mm deep. These are particularly suitable for close centre frames such as wall and floor panels, roof purlins that support cladding, light portal frames, beams and columns (where spans and loads permit), and for lightly loaded and non-structural applications such as support to internal walls and partitions. Increasingly, these sections are being used for whole buildings such as houses, apartments, hotels and offices (page 12), and for modular buildings (page 13). Profiled cladding, floor decks and similar products are also produced by cold rolling.

Steel members can be joined using a wide variety of techniques including welding and bolting (Page 14), and connection design is an important part of any structural system. Connection arrangements can be highly standardised like the structures of which they are part (pages 15 and 16) or unique such as the mast connection for the Commonwealth Games Stadium (page 3). Often in expressed steelwork, connections become important architectural elements in their own right.

This publication provides a simple overview of some of the basic constructional and structural concepts on which most buildings are founded, and also includes selected aspects of associated technologies such as cladding and fire protection.

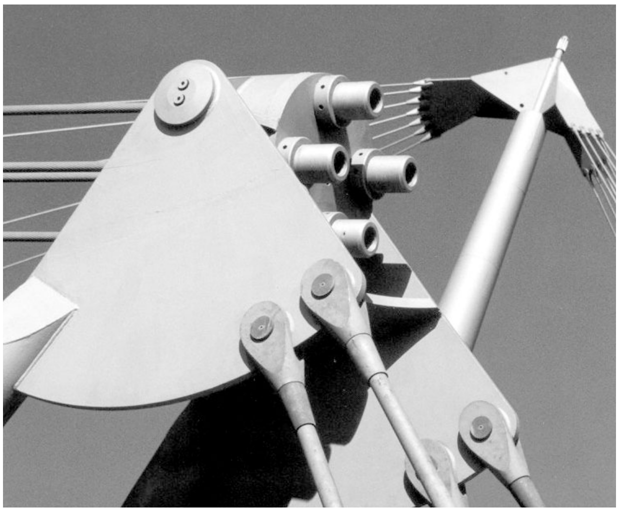
The accompanying CD, aimed at architectural students, contains a concise structures course that can further inform the selection and development of structural solutions.

Curved beams at Helsinki Airport

Yorkon

Murray Grove (front elevation)

Renault Building

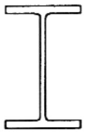
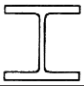
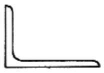
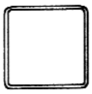
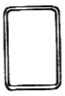
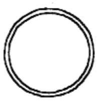


Arup Associates

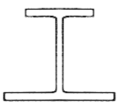
Mast connection, Commonwealth Games Stadium, Manchester

1 PRODUCTS

Hot rolled steel sections

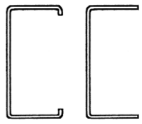
Section	Product	Corus size range (mm)*			Typical Uses
	Universal Beams (UB)	1016 x 305 914 x 419 914 x 305 838 x 292 762 x 267 686 x 284 610 x 305 610 x 229 533 x 210	457 x 191 457 x 152 406 x 178 406 x 140 356 x 171 356 x 127 305 x 165 305 x 127 305 x 102	254 x 146 254 x 102 203 x 133 203 x 102 178 x 102 152 x 89 127 x 76	Beams
	Universal Columns (UC)	356 x 406 356 x 368	305 x 305 254 x 254	203 x 203 152 x 152	Columns
	Parallel Flange Channels (PFC)	430 x 100 380 x 100 300 x 100 300 x 90 260 x 90	260 x 75 230 x 90 230 x 75 200 x 90 200 x 75	180 x 90 180 x 75 150 x 90 150 x 75 125 x 65 100 x 50	Channels Edge beams Secondary steelwork
	Equal angles	200 x 200 150 x 150	120 x 120 100 x 100	90 x 90	Truss members Bracing ties Secondary steelwork
	Unequal angles	200 x 150 200 x 100 150 x 90	150 x 75 125 x 75 100 x 75	100 x 65	Truss members Bracing ties Secondary steelwork
	Square Hollow Sections	400 x 400 350 x 350 300 x 300 250 x 250 200 x 200 180 x 180	160 x 160 150 x 150 140 x 140 120 x 120 100 x 100 90 x 90	80 x 80 70 x 70 60 x 60 50 x 50 40 x 40	Columns Trusses Members subject to torsion
	Rectangular Hollow Sections (RHS)	500 x 300 450 x 250 400 x 200 300 x 200 300 x 100 250 x 150 250 x 100	200 x 150 200 x 120 200 x 100 160 x 80 150 x 100 120 x 80 120 x 60	100 x 60 100 x 50 90 x 50 80 x 40 60 x 40 50 x 30	Columns Beams Trusses Members subject to torsion
	Circular Hollow Sections (CHS)	508 457 406.4 355.6 323.9 273 244.5 219.1	193.7 168.3 139.7 114.3 88.9 76.1 60.3 48.3	42.4 26.9	Columns Trusses Members subject to torsion

Most of these sections are available in a range of cross-sectional thicknesses (usually termed weights). Refer to Corus section tables. Structural Hollow Sections are also formed by cold rolling. These sections are not interchangeable with hot rolled Structural Hollow Sections as the section properties are different.

	Asymmetric Beams ASB	300 ASB (FE) 249 300 ASB 196 300 ASB (FE) 185 300 ASB 155 300 ASB (FE) 153	280 ASB (FE) 136 280 ASB 124 280 ASB 105 280 ASB (FE) 100 280 ASB 74	*Slimdek*® Floor Beams

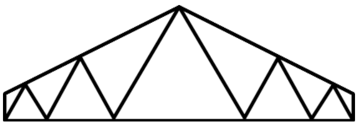
Section designated (FE) can achieve 60 minutes fire resistance without fire protection. Slimdek® is a trade mark of Corus.

Light steel sections (cold formed sections)

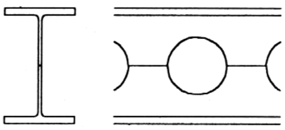
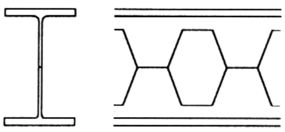
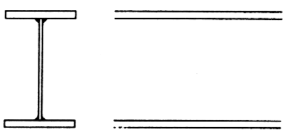
Section	Product	Common UK Size Range*	Typical Uses
	C Section	75 to 300 mm deep	Lipped Structural frames Joists Studs Columns Unlipped Connecting members in panels
	Sigma	130 to 265 mm deep	Sheeting rails Purlins Studs Joists
	Zed	140 to 300 mm deep	Purlins Sheeting Rails

* Cold-formed sections are manufactured by many different companies and size ranges vary. For actual sizes refer to manufacturers' information. Summary information on sizes of channel sections is contained in *Building Design using Cold Formed Steel Sections: An Architect's Guide*, published by The Steel Construction Institute. These sections are typically 1.2 to 3.2 mm thick and are galvanised.

Fabricated light steel lattice trusses

Section	Product	Type size range*	Typical uses
	Lattice Trusses	220 to 3000 mm deep	Floor beams Roof trusses - curved - pitched - parallel chord

Fabricated beams

Section	Product	Type size range*
	Cellular beam	457 to 915 mm deep 1.5 times the depth of the section from which the two halves of the beam are cut.
	Castellated beam	457 to 915 mm deep 1.5 times the depth of the section from which the two halves of the beam are cut.
	Plate girder	Bridge construction, often more than 1m deep (usually without openings) Tapered sections and sections with openings can be used in buildings 400 to 1000 mm deep

* *Fabricated structural sections are manufactured by many different companies and size ranges vary. For actual sizes refer to manufacturers' information.*

Light steel cladding

Profile	Product	Typical proportions*
	Profiled Cladding	Used in roofs and walls Depth 30 to 60 mm Width 900 to 1200 mm
	Liner Sheets	Used in built-up roofs with sheeting above Depth 10 to 30 mm Width 900 to 1200 mm
	Composite Panels	Double skin panels with flat, ribbed or profiled external sheets. Various other materials may be used to provide the required insulation and strength characteristics Typical thicknesses 35 to 100 mm
	Standing Seam Roofing	Permits relative movement of two roof panels Depth 50 to 75 mm Width 300 to 600 mm
	Structural Liner Trays	Used to span between rafters with roof sheeting over Depth 80 mm Width 500 mm

**Cladding profiles are manufactured by many different companies and size ranges vary. For actual sizes refer to manufacturers information.*

Light steel decking (used for composite slabs)

Profile	Product	Typical proportions*
	Re-entrant	Depth 51 mm Distance between dovetail centres 152 mm
	Trapezoid	Depth 46 to 80 mm Distance between trough centres 225 to 300 mm
	Deep Decking	Depth 225 mm Distance between trough centres 600 mm

**Decking profiles are manufactured by many different companies and size ranges vary. For actual sizes refer to manufacturers information.*

2 FRAMING SCHEMATICS

Composite beam

Primary and secondary beams in composite steel frames are rigidly connected to the floor slab using shear studs. This allows the floor slab, and the beams beneath, to act compositely. Beam depths are therefore less than in equivalent non-composite frames.

Floor slabs generally comprise profiled steel floor deck with in-situ concrete cast over the deck.
The deck acts as permanent shuttering and spans in a direction transverse to the secondary beams.

Approximate structural sizing

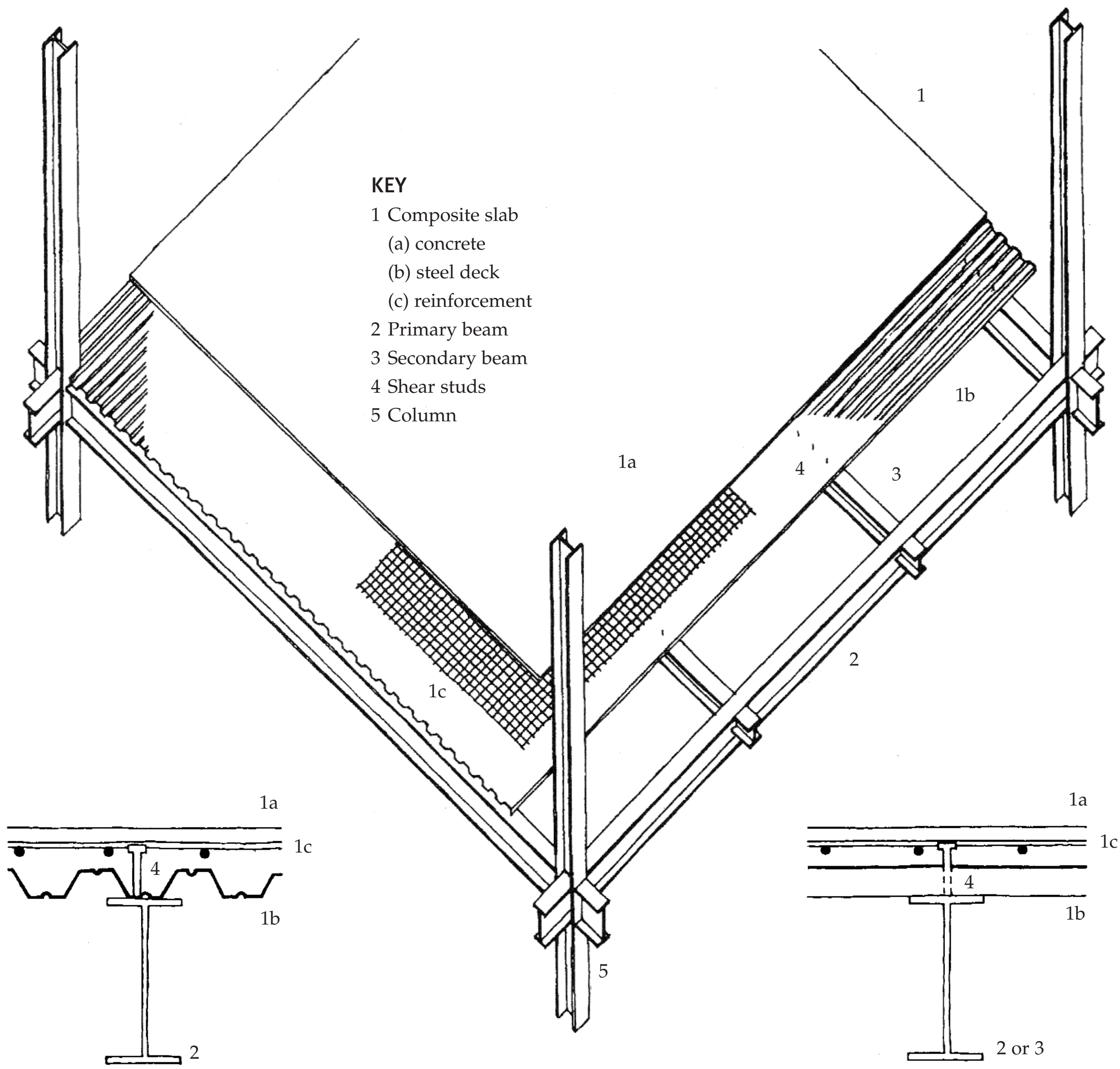
PRIMARY BEAMS	
Maximum span	15 m
Floor beam depth	Span/20
Roof beam depth	Span/25

SECONDARY BEAMS	
Maximum span	12 m
Floor beam depth	Span/25
Roof beam depth	Span/30

Composite slab spans up to 3.6 m

Columns

FLOORS	UC	RHS
1	152 x 152	150 x 150
2-4	203 x 203	200 x 200
5-8	254 x 254	250 x 250
9-12	305 x 305	300 x 300
13-40	356 x 406	400 x 400



View perpendicular to span of floor deck

View parallel to span of floor deck

Slimdek®

Slimdek® comprises an ASB steel section contained within the depth of the slab. It supports deep profiled floor decking. Ties run perpendicular to the beams.

The major advantage of *Slimdek®* construction is that the beams are contained within the floor depth. This reduces the overall height of the floor structure, and can improve service integration.

Asymmetric beams (ASB) are hot rolled sections where the bottom flange is wider than the top flange. Spans of up to 9 m are possible. Some ASB sections have been proportioned so that they can achieve up to 60 minutes fire resistance without applied fire protection.

Approximate structural sizing

PRIMARY BEAMS

Maximum span	9 m
Beam depth	Span/30

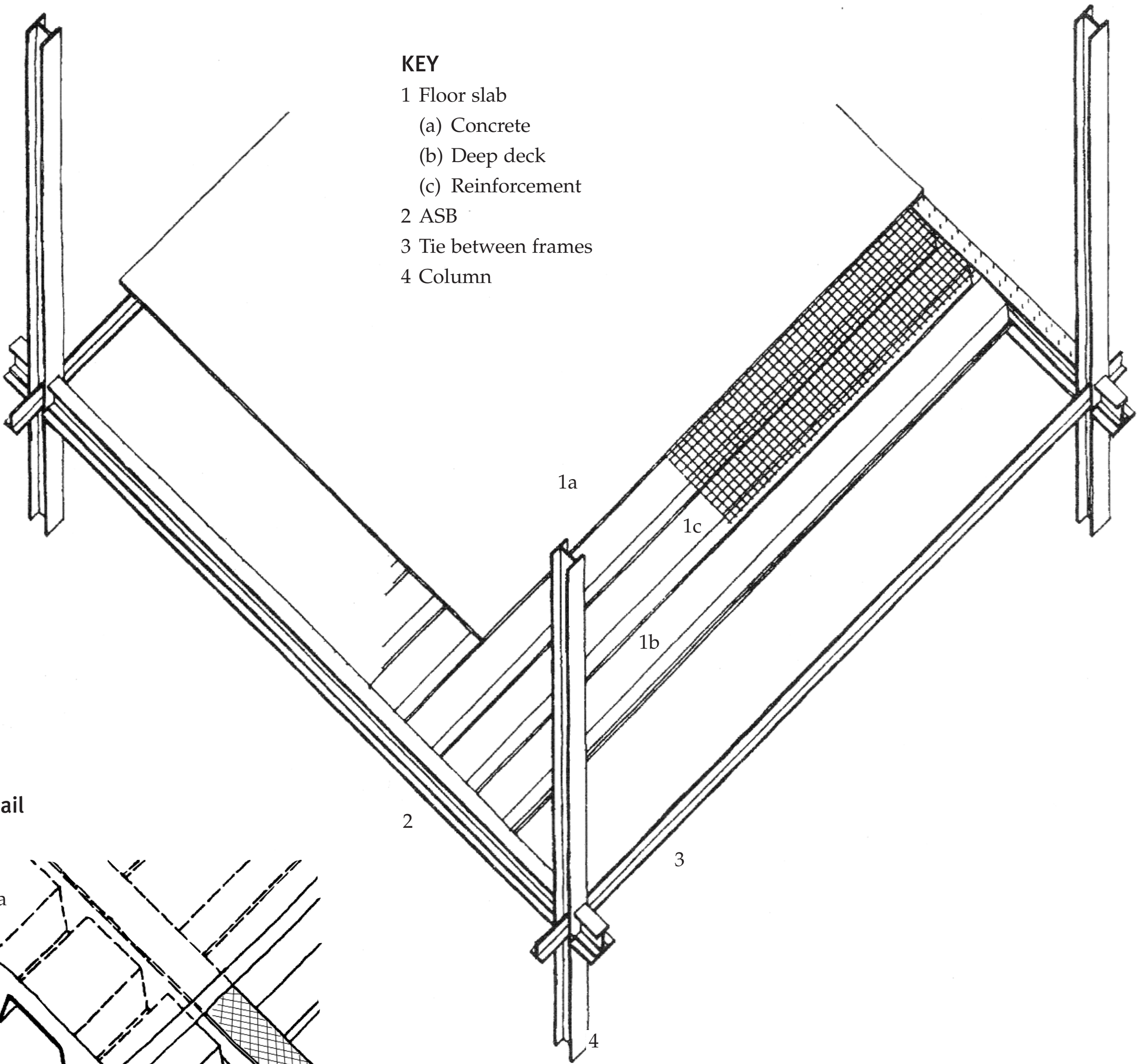
Composite slab spans up to 9 m

Columns

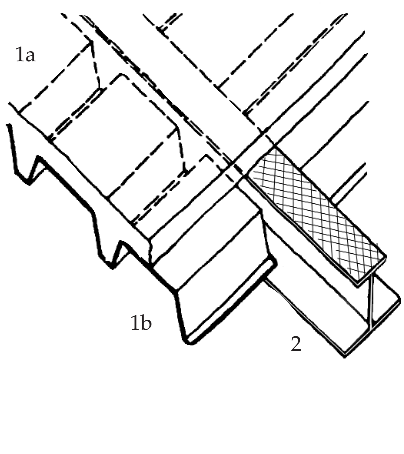
FLOORS	UC	SHS
1	152 x 152	150 x 150
2-4	203 x 203	200 x 200
5-8	254 x 254	250 x 250
9-12	305 x 305	300 x 300

KEY

1 Floor slab
(a) Concrete
(b) Deep deck
(c) Reinforcement
2 ASB
3 Tie between frames
4 Column



Detail



Slimdek® is a trademark of Corus.

Portal frame

Steel portal frames are capable of spanning large distances. They are used in the construction of factories and warehouses, and other low-rise buildings that require wide spans. Wall and roof bracing is normally provided in selected bays, often at the end of buildings. Additional vertical column or beam sections may be introduced at the gables (wind posts) to support cladding on end walls.

Roof beams (rafters) and columns are usually fabricated from hot rolled steel sections, while purlins and cladding rails are usually in light steel sections. Liner trays may be used as an alternative to cladding rails.

Cladding materials include built-up cladding systems (as shown), composite cladding panels, and masonry.

Typical light steel cladding details are provided in Section 4.

Small single storey industrial buildings can also be constructed using light steel sections for the columns and rafters

Approximate structural sizing

ROOF BEAMS (RAFTERS)

Typical span	20-50 m
Beam depth	Span/60

Light steel rafters span up to 18 m

COLUMNS

Column depth	1.25 x roof beam
Width	as UB sections

PURLINS

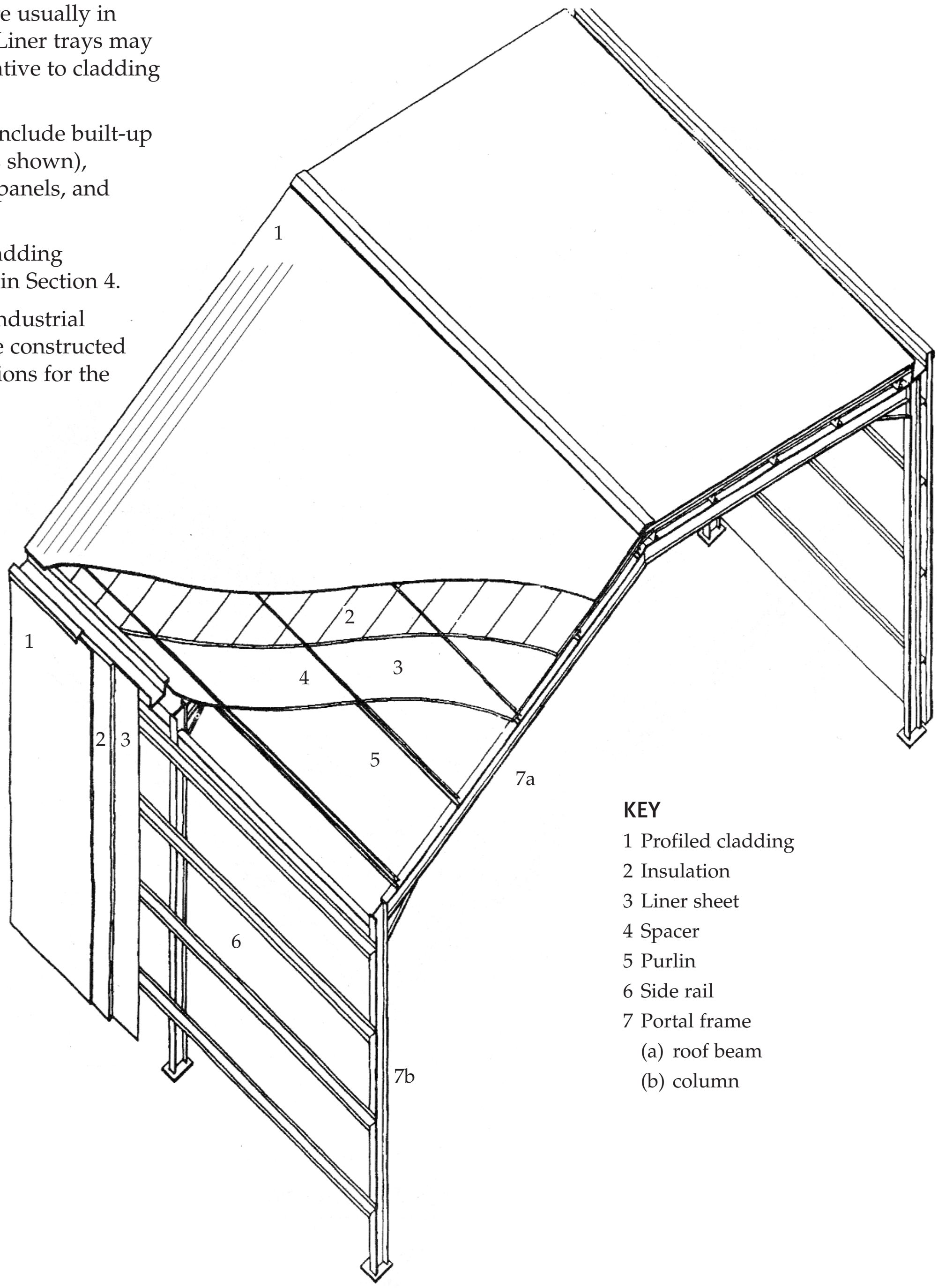
Maximum span	4.5 – 7.5 m
Purlin depth	Span/35

LINER SHEETS

Typical maximum span	3 m
Liner depth	20 mm

PROFILED CLADDING

Typical maximum span	3 m
Profile depth	35 – 40 m



KEY

1 Profiled cladding
2 Insulation
3 Liner sheet
4 Spacer
5 Purlin
6 Side rail
7 Portal frame
(a) roof beam
(b) column

Trusses

Steel trusses are highly efficient structural forms, able to span considerable distances. They are visually light and services can pass through them.

Trusses may be fabricated from a variety of steel sections including: circular, square and rectangular hollow sections, angles, flats, rods and cold-formed profiles. Circular hollow sections are often used for exposed architectural steelwork, and specialist machinery has been developed to cut the complex tube-to-tube connections that arise at nodes where multiple tubes intersect. Columns are generally Universal Column sections (UCs), or Square or Circular Hollow Sections (RHS or CHS).

Trusses may have flat cross-sections (one chord normally above the other), triangular cross-sections, or occasionally may have rectangular cross-sections to accommodate walkways or building services.

The components (members) are usually fully welded, however long members can be fabricated in several sections. Trusses are normally connected to columns using bolts. Where trusses are connected to RHS or CHS sections and it is not possible to install conventional nuts onto the end of bolts inside the section, conventional bolts may be used in specially threaded holes. Alternatively, proprietary bolts may be used that incorporate an expanding sleeve.

Approximate structural sizing

ROOF BEAMS

Depth	Span/15
Typical maximum length	60 m

FLOOR BEAMS

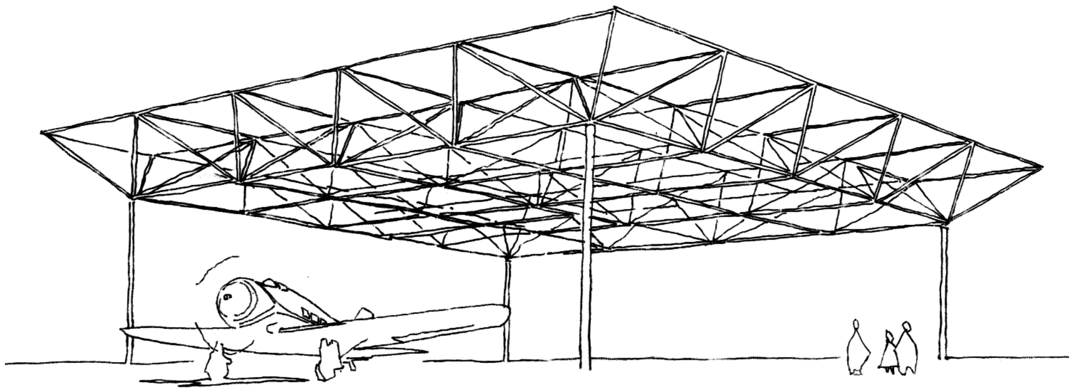
Depth	Span/12
Typical maximum length	10 – 25 m

Space frames

Space frames are essentially three dimensional trusses able to span in two directions. They may be flat for use as roofs, walls or inclined walls, or may be curved to form continuous barrel type roof geometries. Flat frames used as roofs sometimes have slight cambers to direct water to appropriate roof outlets.
Space frames allow for easy service distribution within their depth and can provide light elegant structural solutions.

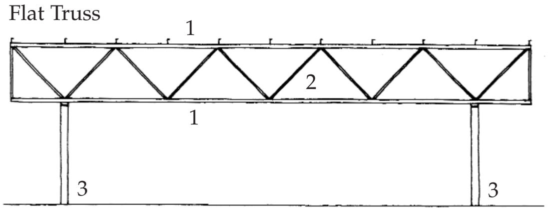
SPACE FRAMES

Depth	Span/40
Clear span	100 m

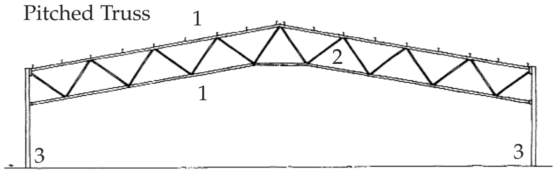


KEY
1 Chord 2 Lattice 3 Column

Flat Truss



Pitched Truss



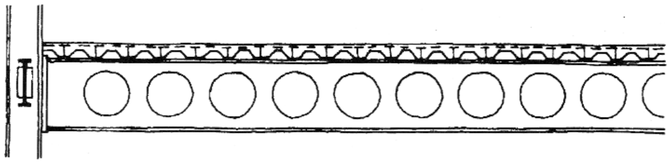
Frank Gehry

Curved roof, Berlin

Long span structures

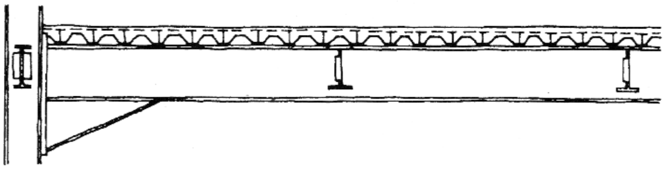
These systems incorporate facility for integration of large building services.

Type:



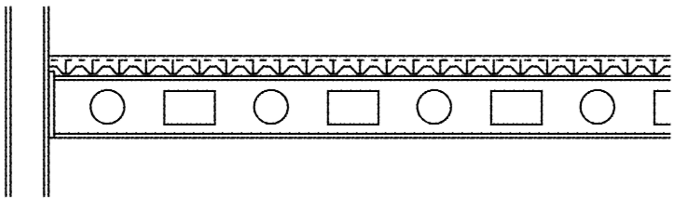
Cellular beams
Perforations lighten sections and provide routes for building services.

Usual maximum span	15 m
Beam depth	Span/22



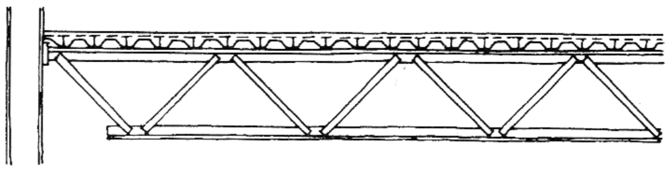
Haunched beams
Rigid connections reduce overall beam depth.

Usual maximum span	18 m
Beam depth	Span/30



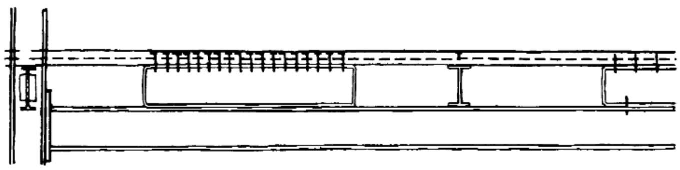
Fabricated beams
Fabricated beams are usually used where long spans are required. The section is fabricated from three plates welded together to form an I-section. It is possible to design these sections with web openings to allow for service integration.

Usual maximum span	15 m
Beam depth	Span/20



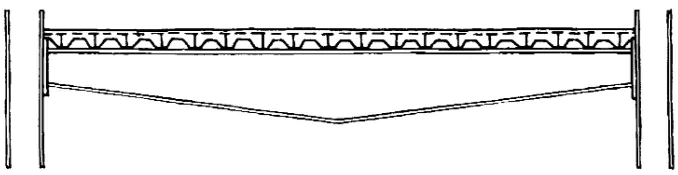
Composite trusses
Trusses connected to floor slab using welded shear studs. Trusses may use tee, angle or hollow sections.

Usual maximum span	30 m
Beam depth	Span/15



Stub girders
Short beam sections are welded to the top of beams and support the floor slab. Services may pass through voids.

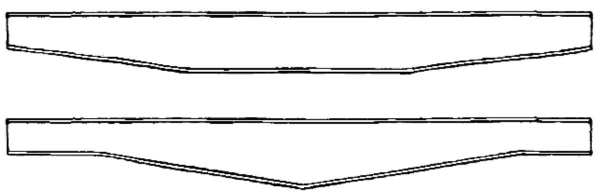
Usual maximum span	20 m
Beam depth	Span/15



Tapered beams
Tapered sections provide service zone adjacent to columns.

Usual maximum span	25 m
Beam depth	Span/20

Alternative tapered beam profiles:



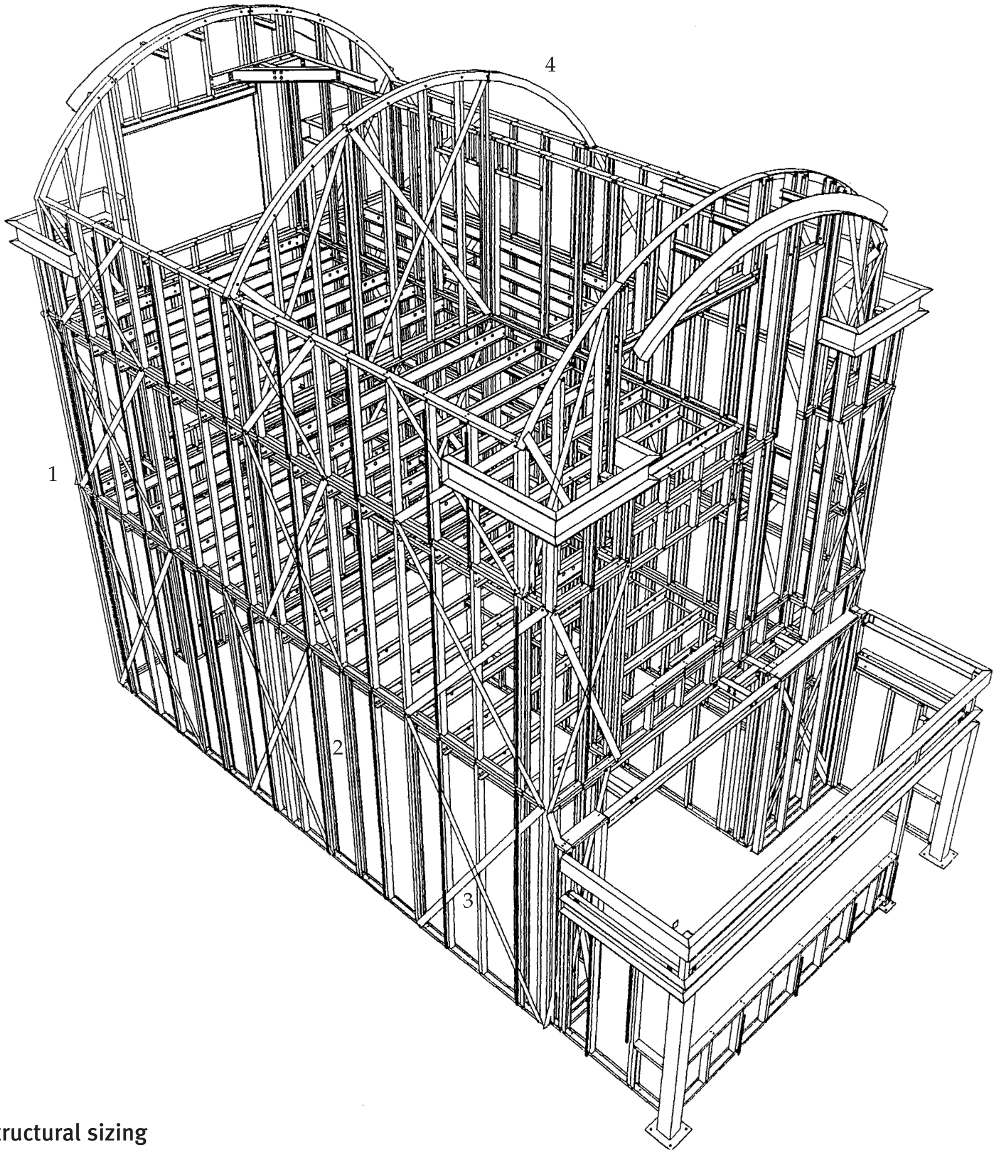
The merit of each of the above systems depends on span, cost, degree of service integration, future adaptability etc.

Light steel frames

Light steel construction uses cold-formed steel channel sections (C-sections) that are much thinner (typically 1.6 to 3.2 mm thick) than hot rolled sections. Light steel sections are produced from galvanized steel. Sections normally range between 75 and 300 mm deep, and are available from various manufacturers.

Light steel frames normally combine many different section sizes and incorporate steel floor joists, beams, columns, stud walls (load bearing) and partitions (non-load bearing). Connections are made using self-drilling, self-tapping screws, welds or bolts.The frame is assembled on site, usually from a series of panels.

Acoustic and fire resistance criteria are important in separating walls and floors. Floor beams may be used in conjunction with composite slabs. Open roof structures may be created using attic type trusses or purlins spanning between flank walls.



KEY

1 Floor joist
2 Stud
3 Bracing
4 Curved rafter

Approximate structural sizing

FLOOR JOISTS (SINGLE C)	
Maximum span	5 m
Spacing	450 or 600 mm
Joist depth	Span/25
Thickness	1.6 – 2.4 mm

BEAMS (DOUBLE C)	
Maximum span	6 m
Beam depth	Span/18
Thickness	2.4 – 3.2 mm

STUDS (SINGLE C, 2 STOREY BUILDING)	
Spacing	450 or 600 mm
Depth	75 – 100 mm
Thickness	1.6 – 2.4 mm

COLUMNS (DOUBLE C, 3-STOREY BUILDING)	
Spacing	4 – 6 m
Depth	150 – 250 mm
Thickness	2.4 – 3.2 mm

Modular construction

Modular construction, sometimes called volumetric construction, allows buildings or substantial parts of buildings, to be constructed in a factory environment. Wall, floor and ceiling frames can be manufactured efficiently using light steel sections. Wall frames typically comprise vertical steel studs with top and bottom tracks, and either bracing or sheathing boards to prevent racking. Floor and wall cassettes comprise horizontal joists connected together at both of their ends with a channel or similar section. Alternatively they may be constructed in-situ from individual members.

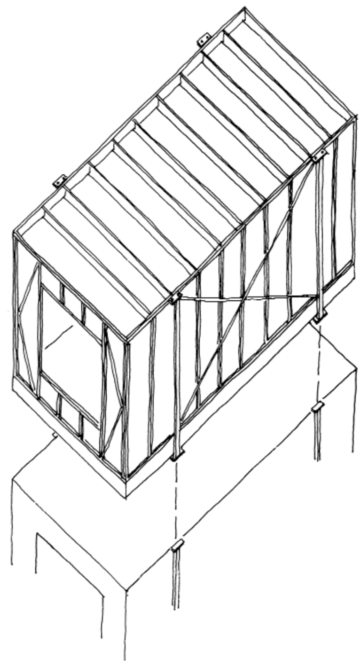
Two types of module are commonly used: modules with columns that transfer forces as point loads, and modules with load bearing walls that transfer vertical forces along their length in a similar fashion to conventional load bearing construction.

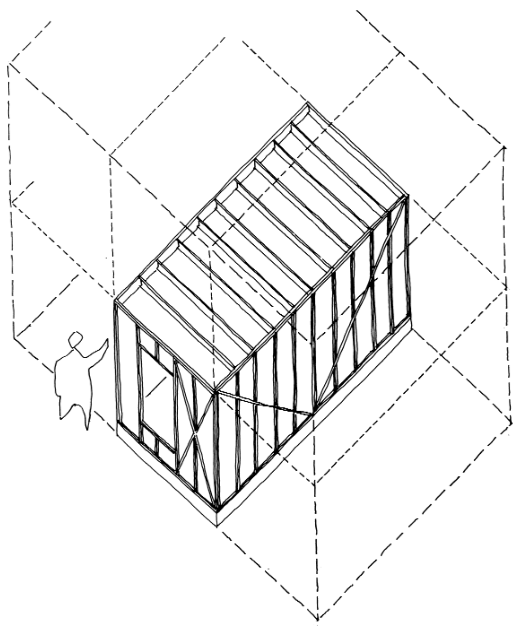
The size of modules is usually determined by transport and lifting criteria. Hotel rooms, student study-bedrooms and bathrooms are normally built as single modules, whilst larger spaces, such as payment areas, shops at filling stations and fast food restaurants are generally constructed from several open sided modules installed side by side.

Other important applications of modular construction include prefabricated plant rooms and toilets.

Structural sizes are similar to those given for light steel frames in the previous section.

Hybrid modular construction involves the use of modules with panels or conventionally constructed building elements. Houses, for example, may be constructed with modules for those areas that require complex fitting-out such as kitchens, bathrooms and staircases, whilst the remaining areas (sometimes termed baggy space) are constructed using panels or built in-situ.





Yorkon

Murray Grove under construction

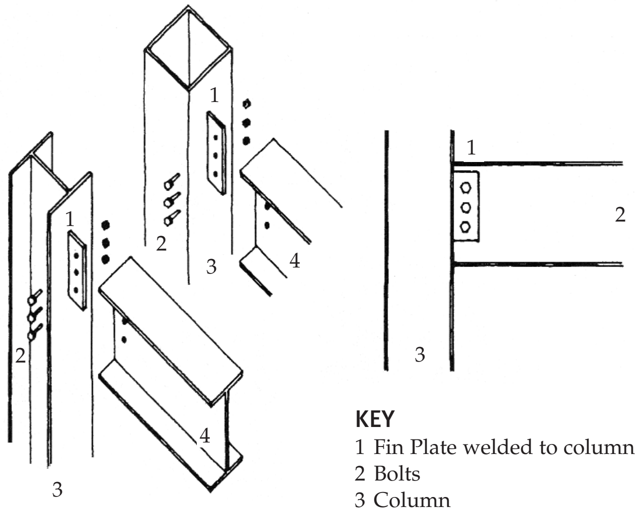
Yorkon

Murray Grove (rear elevation)

3 CONNECTIONS

Fin plate beam-to-column connection

Fin plate connections are fabricated by welding a single plate to the column. Beams are normally attached using two or more bolts. Where necessary, adjustment can be provided using slotted holes (for instance horizontally slotted holes in the web of the section attached to the fin plate).



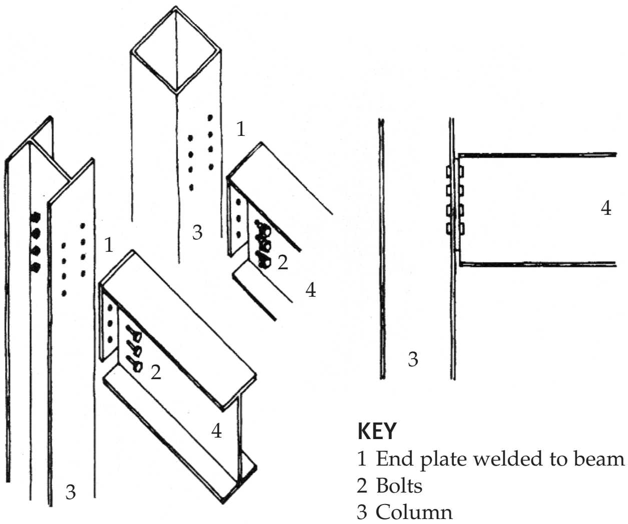
KEY
1 Fin Plate welded to column
2 Bolts
3 Column
4 Beam

End plate beam-to-column connection

Endplate connections have a single plate welded to the end of the beam, which is bolted to the column using two or more bolts arranged in pairs.
Where necessary, adjustment can be provided by slotted holes and shims between the endplate and the section to which is attached.

When connections are made to hollow section columns, it is not possible to install conventional nuts onto the ends of bolts inside the section. Specially threaded holes using the 'Flowdrill'* method or proprietary bolts that incorporate an expanding sleeve may be used.

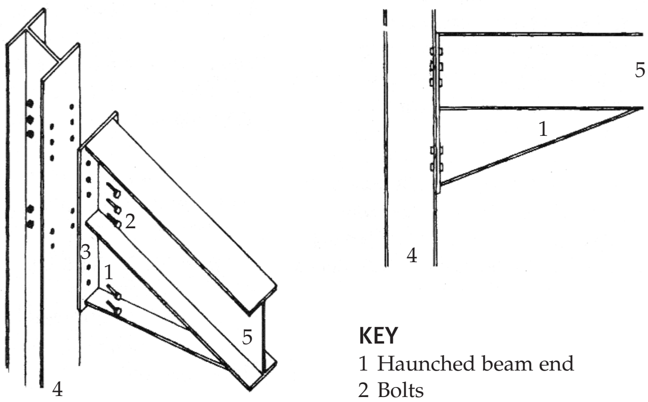
**'Flowdrill' is a trademark of Flowdrill BV.*



KEY
1 End plate welded to beam
2 Bolts
3 Column
4 Beam

Haunched beam-to-column connection

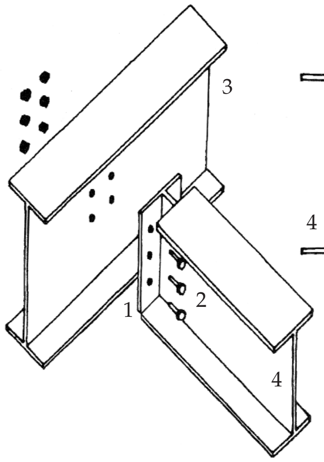
Haunched connections are used where there is a need to achieve high moment transfer. The haunch locally increases the effective depth of the section. Beams are attached using multiple pairs of bolts through an endplate. Little adjustment is possible. Haunched connections are common in portal frames.

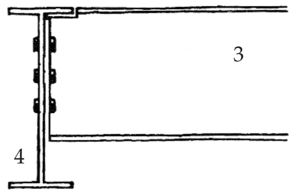


KEY
1 Haunched beam end
2 Bolts
3 Endplate
4 Column
5 Beam

End plate beam-to-beam connection

The end plate beam-to-beam connection is similar to the beam-to-column endplate connection. However because the top flanges of the beams support floors or roof structure directly, the top flange at the end of the incoming beam has to be notched. An alternative detail is to provide a projecting welded bracket or fin-plate on the supporting beam. Adjustment is similar to the beam-to-column detail.

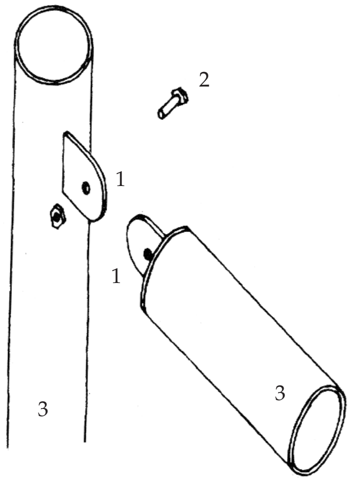


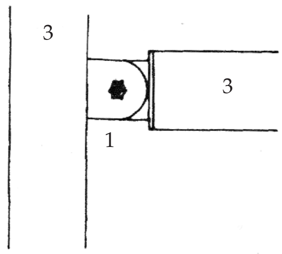


KEY
1 End plate welded to supported beam
2 Bolts
3 Supported beam
4 Supporting beam

Pinned tube connection

The ends of tubes can be profiled and welded, or can be bolted using simple fin-plates. Single fin-plates may be welded to each of the members or, where eccentricities need to be minimised, a single finplate on one member may be designed to locate between a pair of fin-plates on the other (as shown). Attachment is normally made using either bolts or pins.

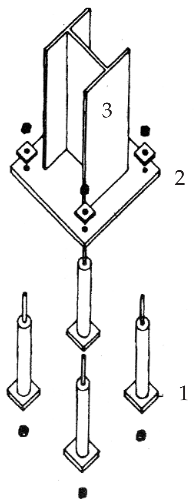


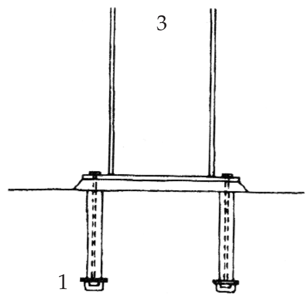


KEY
1 Fin-plate
2 Bolt or pin
3 Tubular section

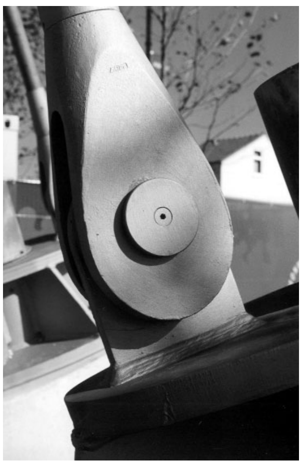
Column base connection

There are a variety of ways of connecting column baseplates to concrete ground structures. One common method involves casting bolts, via bolt pockets, into the concrete. Bolts are able to move slightly within the pockets to provide horizontal adjustment of the baseplate before grouting the gaps around the bolts. Vertical adjustment is by shims or packs inserted between the baseplate and the top surface of the concrete.





KEY
1 Bolt pockets cast in concrete
2 Base-plate
3 Column



Arup Associates

Mast base and pin, Commonwealth Games Stadium, Manchester

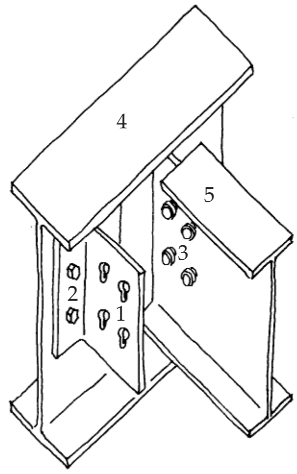
Quicon™ connection

The Quicon™ connection uses a special connector component that eliminates the need for onsite bolting. It can be used for beam to column or beam to beam connections. The supporting member, either a beam or column, is fitted with a fabricated tee piece using ordinary structural bolts. The tee piece is fabricated with key-hole shaped slots. The special connector is bolted to the supported beam prior to erection.

Using this type of connection improves the speed of erection, which results in reduced construction costs. Safety on-site is also improved, as site operatives spend less time aloft and do not need to carry equipment with them.

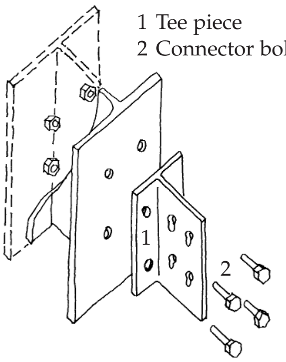
Beam to Beam

KEY
1 Tee piece
2 Connector bolts
3 Special connectors
4 Supporting beam
5 Supported beam

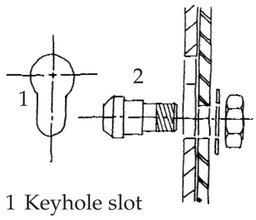


Fabricated Tee Piece

1 Tee piece
2 Connector bolts



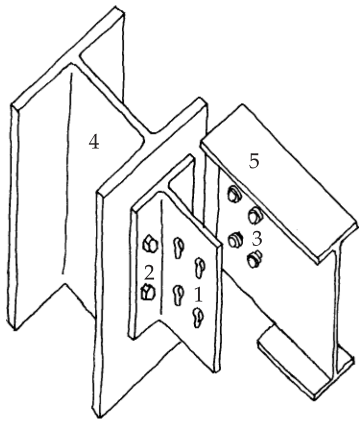
Special Connector



1 Keyhole slot
2 Special connector

Beam to Column

KEY
1 Tee piece
2 Connector bolts
3 Special connectors
4 Column
5 Supported beam

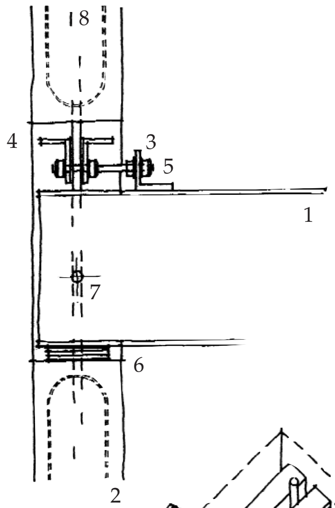


Steel-to-concrete connection

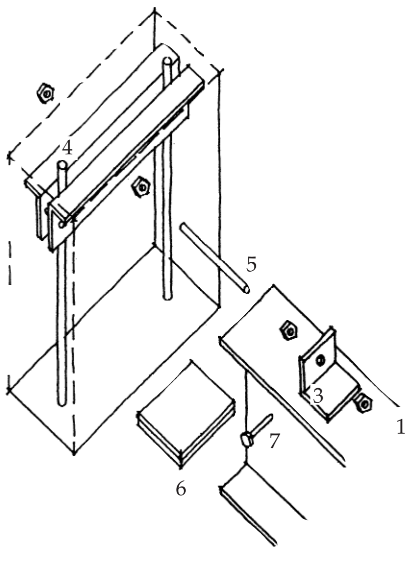
Many building and refurbishment projects require structural connections between steelwork and concrete construction. For example, a multi-storey building with a steel frame may rely on a concrete core for stability; this requires fixings to be made between the steelwork and the concrete.

For new construction, connections are usually made using a steel bracket, which can be cast into the concrete element prior to erection of the steelwork. Care should be taken to ensure that the connection can be made quickly and safely during erection and sufficient adjustment is provided to meet erection tolerances.

In refurbishment work, connections to existing concrete structures can present particular difficulties. Post-drilled expanding anchors or resin anchors are commonly used, but these must be positioned so that they do not clash with reinforcing bars. This may mean that slotted holes are required in the fixing bracket or the fixing bracket must be fabricated after suitable locations for the post drill anchors are determining on site.



KEY
1 Steel beam
2 Concrete wall
3 Bracket welded to beam
4 Reinforcement bracket clamp*
5 Connecting rod
6 Shims on grout bed
7 Shear connector*
8 Local additional reinforcement
*Option, do not omit both 4&7



4 CLADDING SCHEMATICS

Strongback system

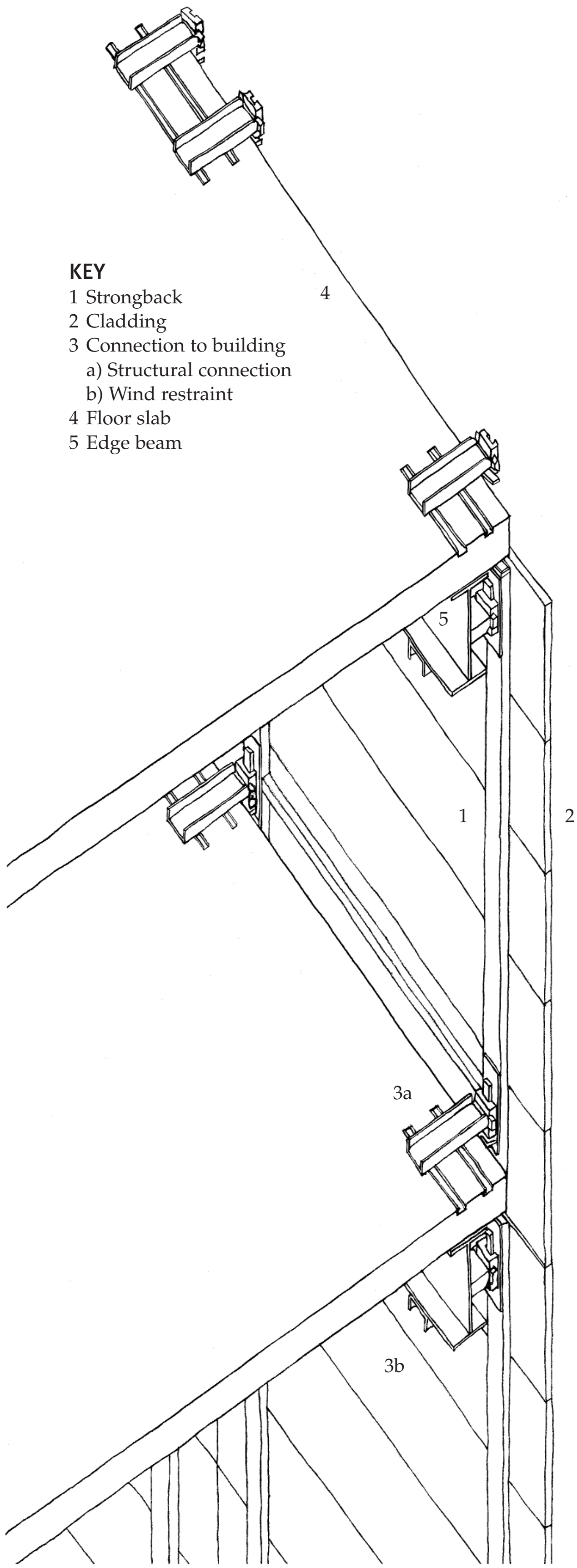
Strongback cladding systems have a sub-frame that supports thin cladding panels. Units are normally storey height and up to 6 – 9 m wide. They are fixed either to the edge of the floor slab or to the floor edge beams or to columns. The supporting frame is usually constructed from either hot rolled or light steel sections. Cladding materials include stone, coated steel and stainless steel.

Panels are normally fixed to the building at four points (two points at the top of the panel and two at the bottom). They may be either hung from the top connections or may bear on the bottom connections. Connections carrying the self-weight of the panel are termed structural. Other connections act as wind restraints and prevent swaying, or overturning of the panel, depending upon whether the panel is top hung or bottom supported. Provision is made at the fixings for building movements and tolerances.

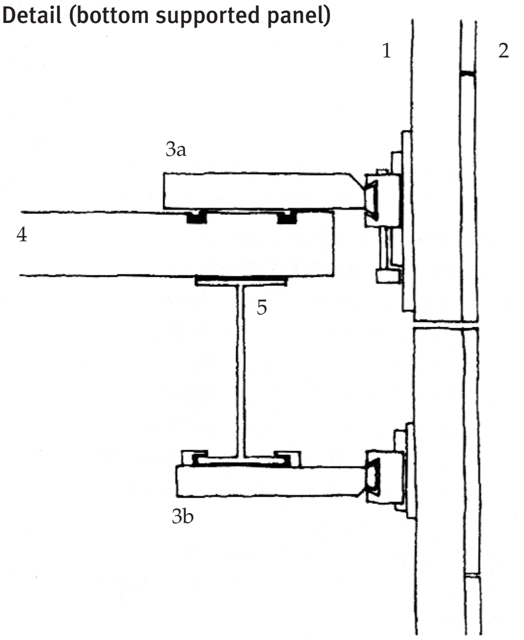
Since panels can be relatively large, it is possible to clad buildings rapidly by using storey-high units.

KEY

1 Strongback
2 Cladding
3 Connection to building
   a) Structural connection
   b) Wind restraint
4 Floor slab
5 Edge beam



Detail (bottom supported panel)

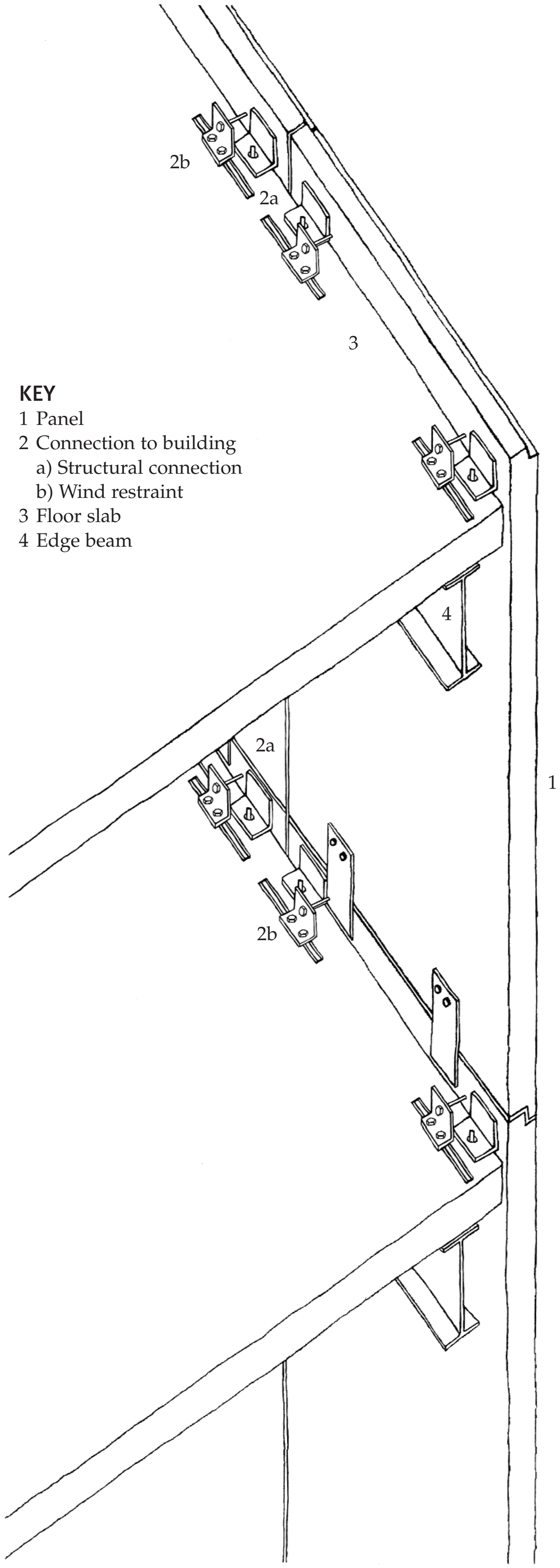


Integral panels

Integral cladding panels are generally made from concrete, and are able to support their own weight and resist wind loads without additional framing. As a result they tend to be heavier than strongback panels (typically around 300kg/m^2). Panels are normally storey height and between 3 and 9 m wide.

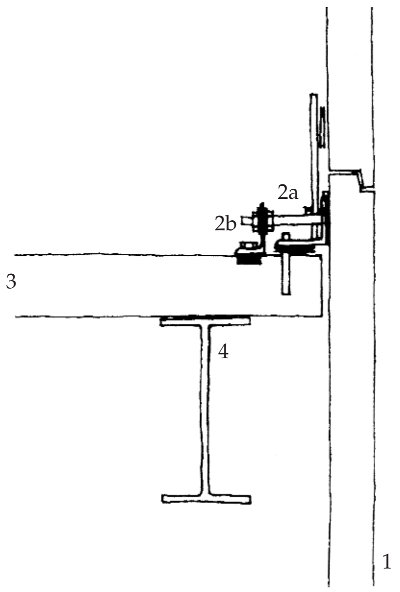
They may be clad in other materials such as stone or ceramic tiling. Panels may be top hung or bottom supported and, like strongback panels, are normally fixed to the building at four points (two points at the top of the panel and two at the bottom). Panels typically bear on the slab edge using 'boots' (projecting concrete nibs) or bolted-on brackets.

Two structural connections are normally made at the points of bearing, with two wind restraint connections at the opposite edge (refer to strongback description for definitions). Bolted on brackets take up less, space which is particularly advantageous in buildings without raised floors where boots can be difficult to accommodate.



KEY
1 Panel
2 Connection to building
  a) Structural connection
  b) Wind restraint
3 Floor slab
4 Edge beam

Detail (top hung panel)



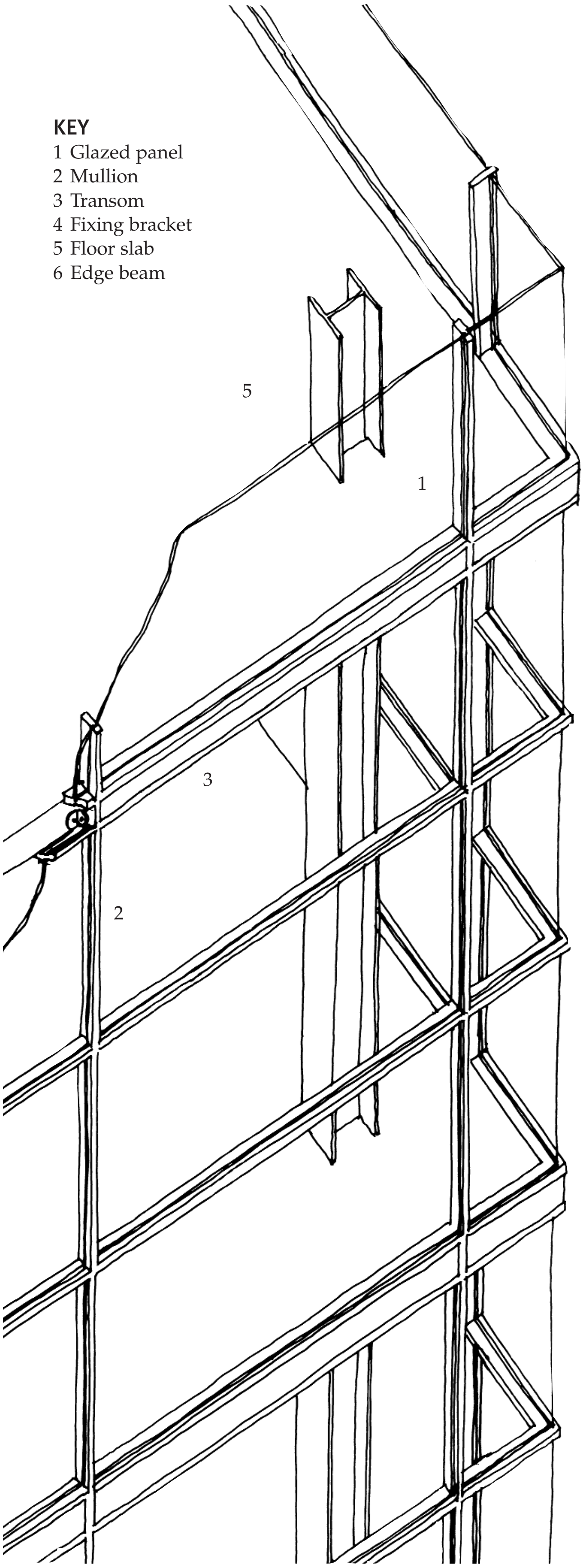
Stick system

Stick cladding systems comprise a series of vertical members (mullions) and horizontal members (transoms) that form a grid. This grid is used to restrain either solid panels or glass using rubber gaskets, and is normally fixed to the floor edges by specially designed brackets, which provide wind restraint (refer strongback description for definitions). The self-weight of the cladding is normally taken to the ground through the mullions.

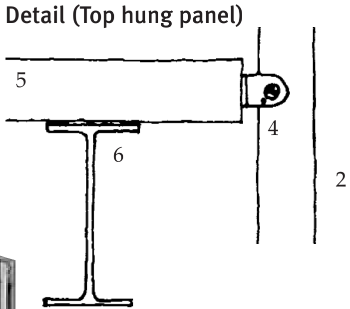
Stick systems are amongst the lightest forms of cladding (typically 50 kg/m^2). Mullion spacings are normally in the range 1.2 – 2 m, although wider spacings are possible. Transom spacings are normally determined by panel requirements and the architectural treatment of the façade.

Stick systems can be 'unitised' whereby horizontal and vertical members are prefabricated into units, which are craned onto the façade. Special edge members have been developed for these systems.

KEY
1 Glazed panel
2 Mullion
3 Transom
4 Fixing bracket
5 Floor slab
6 Edge beam



Detail (Top hung panel)



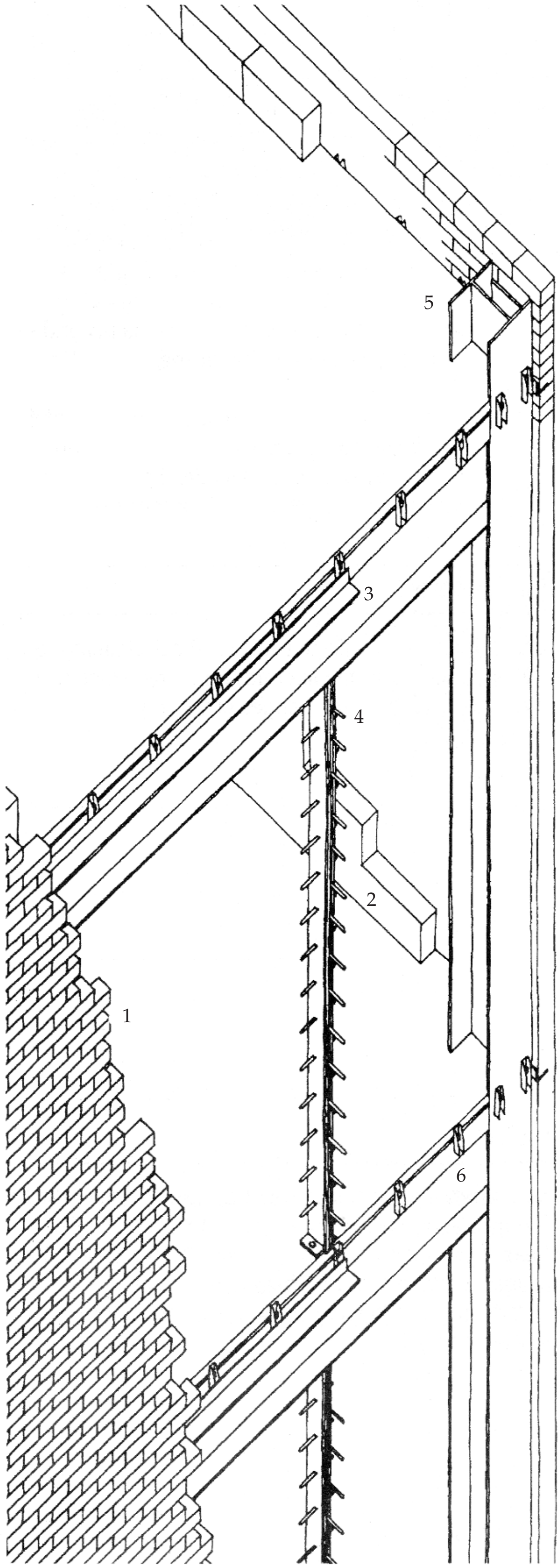
Rautaruukki Oyj

Kone Building

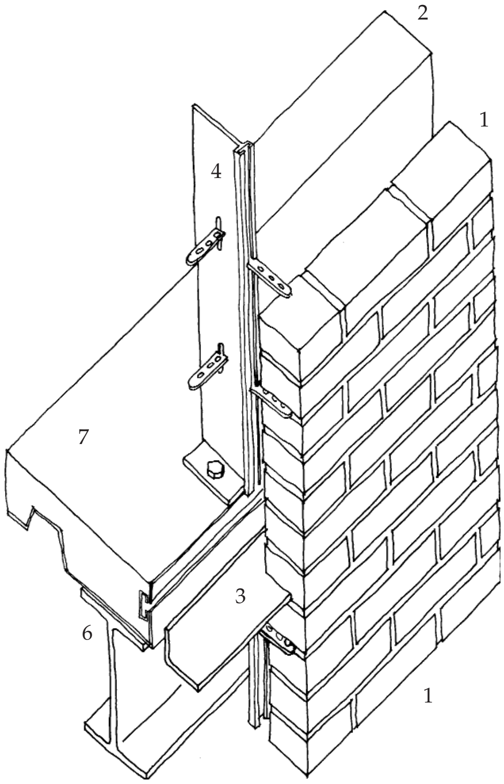
Brick

Multi-storey frames may be clad in brickwork or stone using a range of proprietary systems based on specially designed brackets and restraint devices.

The most common method of attaching brickwork to steel frames is by the use of shelf angles fitted either to the slab edge, or to plates welded onto the edge beams. The shelf angles are usually made from stainless steel. The method of attachment of the shelf angle allows for vertical adjustment to suit the brick coursing. Brickwork is constructed on these shelf angles and attached to the columns and to inner concrete block walls using brick ties. Windposts are sometimes incorporated to give improved stability, particularly in tall buildings subject to high wind pressures, or where large size panels are used. An expansion joint is used at the top of the panels to take up relative movements between the building frame and the brickwork.



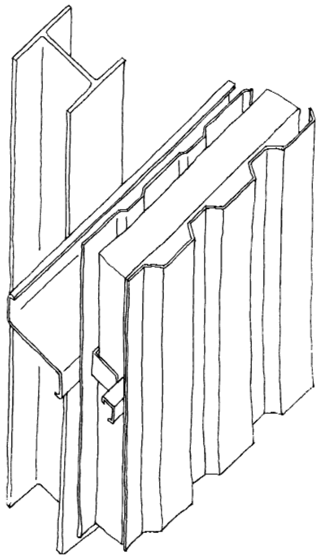
KEY
1 External brickwork
2 Internal brickwork
3 Shelf angle
4 Windpost
5 Column
6 Edge beam
7 Floor slab



Light steel cladding

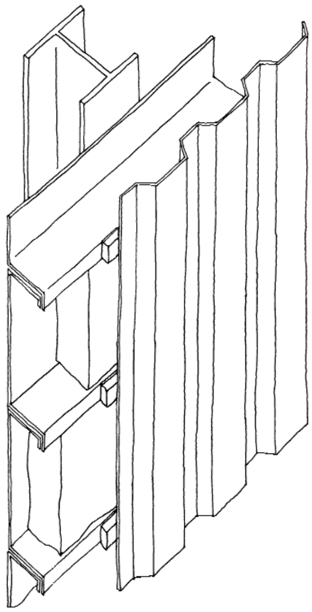
Built-up system with liner sheet

These systems comprise two separate cladding sheets: an external sheet, which is coloured and highly profiled, and a more lightly profiled inner liner sheet. The sheets are separated by spacer rails and insulation. The liner sheet and spacers are fixed to cladding rails that span between columns. The external sheet is fixed to the spacer. The normal method of attachment is by self-drilling, self-tapping screws.



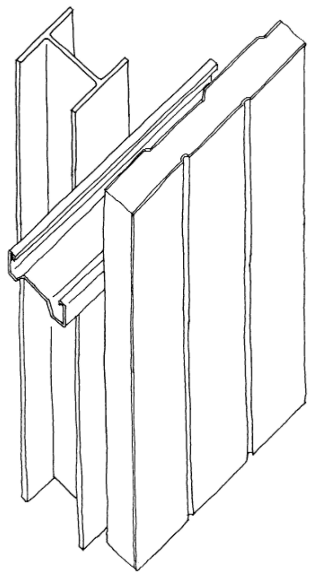
Built-up system with liner trays

Liner trays span between columns and replace the liner sheet, cladding rails and spacer rails. Insulation is set within the liner trays and the external cladding sheet is fixed directly onto the outer flanges of the tray.



Composite panel system

Composite panels have a sandwich construction comprising two steel sheets bonded either side of an insulating core of foam, mineral fibre or similar material. The bonded panel produces good stiffness, and both profiled and smooth surfaces are available. Panels may be fixed using a variety of techniques including self-drilling, self-tapping screws, and secret-fixing brackets located within the panel joints.

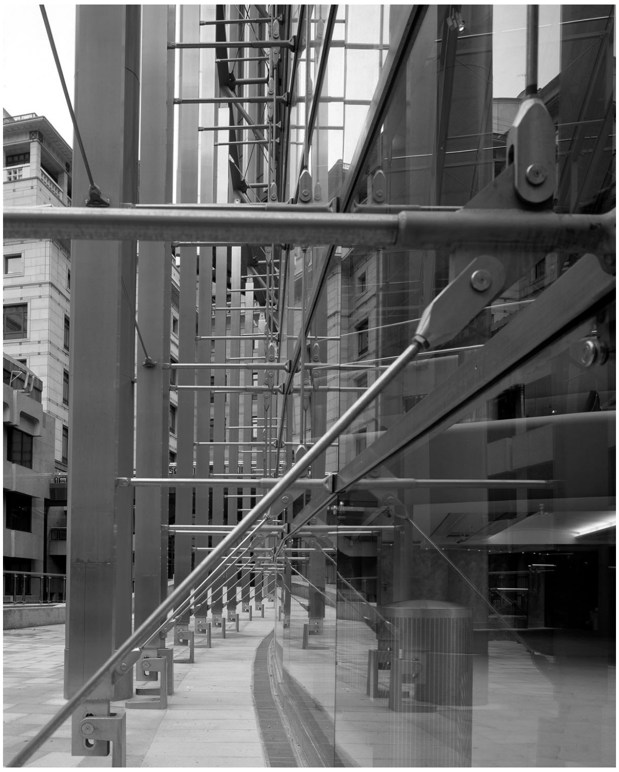


Bolted glazing systems

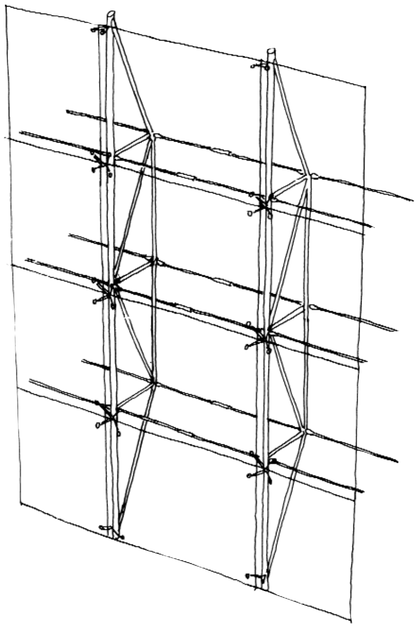
The use of sophisticated bolted glazing systems, where glass panels are attached directly to structural steelwork without using any intermediate framing, has grown significantly in recent years. Bolts attach the glass to brackets on the steel through pre-drilled holes in the glass panes. The bolts provide point support instead of the continuous edge support given by conventional frames.

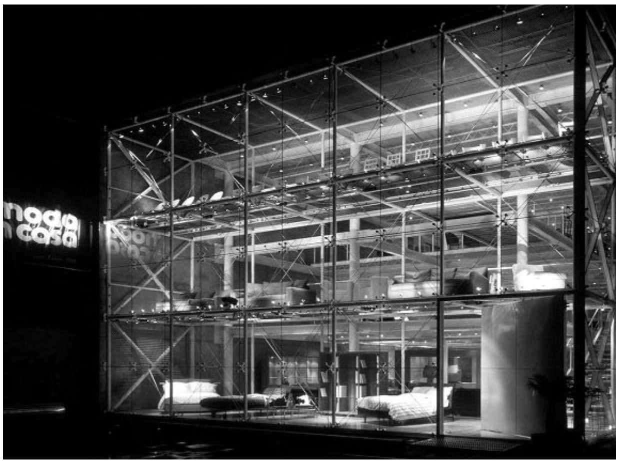
Vertical glazing panels, up to 2 m x 2 m, can generally be supported using four corner fixings, whilst larger panels, up to 2 m x 4 m, typically require 6 fixings. Horizontal and inclined glazing may require more frequent supports.

Various types of bolted fixing have been developed. These include simple bolts, where the head is proud of the surface of the glass, and countersunk designs that are recessed into the glass. Articulated fixings are often used in conjunction with large panes on tall or long span, steel structures. As the glass panels and the supporting structure bend under the combined effects of self weight and applied loads, articulated bolts allow some rotation of the fixing.



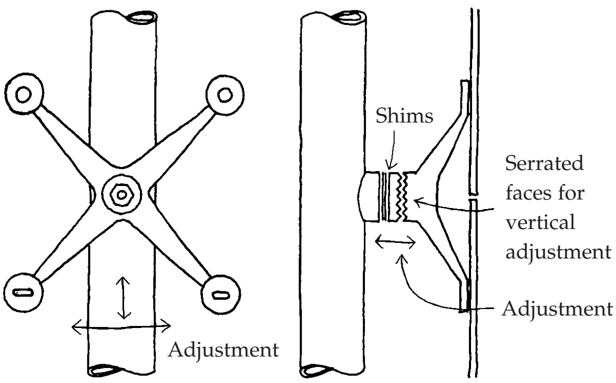
Glazed entrance hall, NatWest Tower, London





Moda in Casa, Mexico City

Architect: E. Norten
Structural Engineer: M. Eekout/Octatube Space Structures.



Spider fixing detail

Buro Happold

5 FIRE PROTECTION

There are four common methods of fire protecting structural steelwork; intumescent coatings, board based systems, sprayed materials and concrete encasement or filling.

Intumescent Coatings
Intumescent coatings may be brushed or sprayed onto steelwork rather like paint. The materials expand when subjected to fire and form an insulating foam. Intumescent coatings can achieve up to 120 minutes fire resistance, and are used mostly on exposed steelwork.

Board Systems
Board based systems are used to form rectangular encasements around steel members, such as internal beams and columns. Paint or other finishes can be applied directly to the boards. The level of fire resistance achieved depends on the type and the thicknesses of the boards used and on the method of attachment.

Sprayed Materials
Sprayed fire protection systems are usually based on cementitious materials and are applied directly onto the surface of steelwork. They are generally low cost, but cannot receive finishes owing to their coarse uneven texture. Sprayed materials tend to be used where steelwork is concealed or where appearance is unimportant. Fire resistance is similar to that of board based materials.

Concrete Filled Structural Hollow Sections
Structural Hollow Sections (SHS) can be fire protected by filling with reinforced concrete. Concrete filled structural hollow sections can achieve 120 minutes fire resistance.

Slimdek®
The *Slimdek®* system has inherent fire resistance as the ASB section is encased in concrete with only the bottom flange exposed to fire. Without fire protection *Slimdek®* can achieve 60 minutes fire resistance.

Periods of fire resistance in excess of 120 minutes can be achieved if the bottom flange is fire protected.

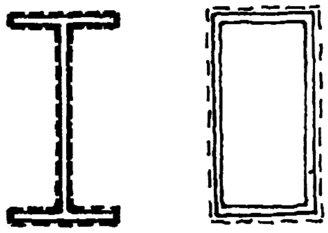
Multi-storey frames requiring 30-60 minutes can have 40% of the floor beams unprotected by following the recommendations of a special design guide.

Protection thicknesses
The section factor of a particular steel section is its surface area per unit length divided by its volume per unit length (A/V). This parameter defines how quickly a steel section will heat up when subjected to fire. The section factor for a member with box protection is lower than that for a member with profile protection, and hence box protected steelwork heats up more slowly and requires less protection.

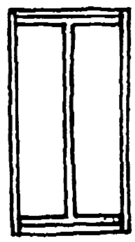
Typical spray or board thicknesses for a column in a multi-storey building are as set out in Table 1, below.

Table 1: Typical spray or board thicknesses based on 254UC x 89 kg/m column in a multi-storey building.

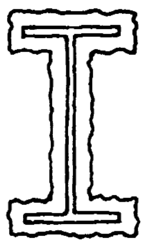
Fire resistance (minutes)	Profile protection (mm)	Box protection (mm)
30	10	12
60	18	15
90	24	20
120	30	25



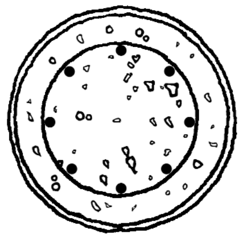
Intumescent coatings



Board based system



Sprayed materials



Concrete filling

6 FURTHER READING

Cladding

Colorcoat in buildings: A guide to architectural practice. British Steel Strip Products, 1990

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