STEEL BUILDINGS IN EUROPE

Multi-Storey Steel Buildings
Part 1: Architect's Guide

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FOREWORD

This publication is the first part of the design guide, *Multi-Storey Steel Buildings*.

The 10 parts in the *Multi-Storey Steel Buildings* guide are:

Part 1: Architect's guide
Part 2: Concept design
Part 3: Actions
Part 4: Detailed design
Part 5: Joint design
Part 6: Fire Engineering
Part 7: Model construction specification
Part 8: Design software – section capacity
Part 9: Design software – simple connections
Part 10: Software specification for composite beams.

Multi-Storey Steel Buildings is one of two design guides. The second design guide is *Single-Storey Steel Buildings.*

The two design guides have been produced in the framework of the European project "Facilitating the market development for sections in industrial halls and low rise buildings (SECHALO) RFS2-CT-2008-0030".

The design guides have been prepared under the direction of Arcelor Mittal, Peiner Träger and Corus. The technical content has been prepared by CTICM and SCI, collaborating as the Steel Alliance.

Contents

SUMMARY

For centuries, steel has demonstrated all its advantages as a construction material for use in famous buildings in the world, but steel is not only a material that delivers technical prowess. It has so many qualities that simply make it the preferred material of architects, especially for multi-storey buildings. This publication has been drafted by architects for architects. It provides information on the material and on the industrial components. It gives the bases of good practice in order to achieve maximum benefit in using steel, in terms of structural behaviour of steel frames, the building envelope, acoustic and thermal performances and sustainable construction.

1 INTRODUCTION

What do Claude Perrault's Louvre colonnades (1670), Mies van der Rohe's Lake Shore Drive apartment towers (1951), Soufflot's Church of St. Genevieve in Paris (1759), Piano and Roger's Georges Pompidou Centre (1977) and Jean Nouvel's Hôtel Industriel in Pantin (1990) all have in common? Each one bears testimony to the great epic of metal in construction.

Of course, the transformation from iron used as structural reinforcement and decoration to the light and airy steel frame which we know today was a very long process. It encompassed no less than 300 years of historical progress, innovation, imagination and creativity: on the part of architects, who introduced new shape grammars with cast iron, iron and then steel; on the part of engineers, whose technical expertise and imagination played a major role in the building of new structures which were once thought of as impossible, even utopian; and on the part of manufacturers, who have worked tirelessly on the development of new materials and products.

Three hundred years of passion for metal: a passion which has been expressed in different ways. Cast iron, once used in buildings, was expensive, heavy and brittle, and provided a very special kind of structural reinforcement dictated by the style of that period: enormous proportions, with iron staples used to hold together blocks of stone to ensure the building's stability.

Today's enthusiasm for iron and steel is very different. Iron brought about transformations in design and the introduction of standard profiles (I, T and L). Thanks to riveting, profiles could be assembled in numerous ways to create all sorts of structures. A landmark achievement was Joseph Paxton's Crystal Palace (1851), the predecessor of modular architecture with its prefabricated building components.

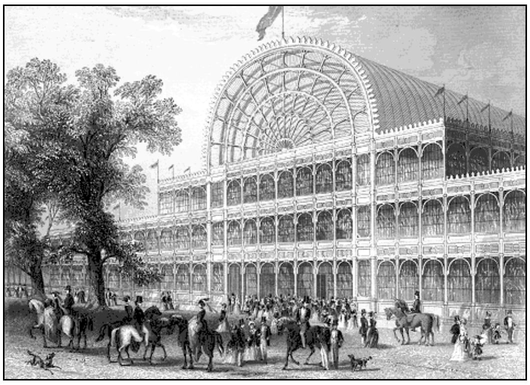


Figure 1.1 Crystal Palace, London

Steel has been in the vanguard of new assembly processes, rolling techniques and computational modelling. It has made possible the use of large spans in construction, for example in industrial buildings (La Samaritaine department store in Paris, which opened in 1917), and in infrastructure and transportation (The Forth Railway Bridge in Scotland, 1890).

Steel is not just a material aimed at technical prowess! It has many qualities that make it the preferred material for architects. It is economical and provides great mechanical functionality; it permits the design of structures which are graceful, light and airy; it streamlines construction site processes; and offers rapid execution. A major advantage, however, is the infinite freedom for creation which it affords the architect. The combinations of different products lend themselves to rich and varied types of construction. When combined with glass, steel makes fabulous use of light and space.

This document, which is aimed at architects, provides an overview of the advantages of steel in construction for multi-storey buildings as well as best practice for this type of structure. Whatever the architect's project, residential buildings, offices, schools, cultural buildings, retail or industrial buildings, the designer should read this document. It addresses:

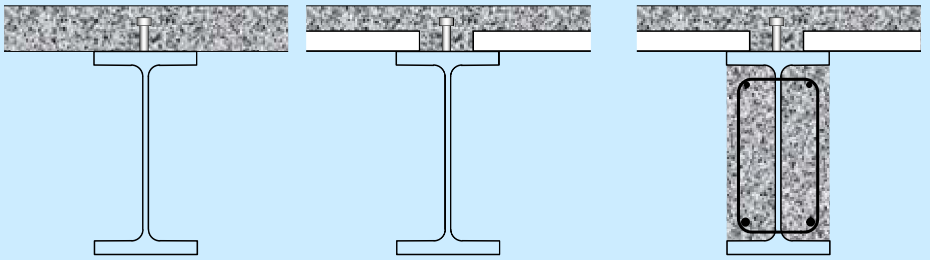
- The material, its qualities and market products
- The structure (how to design)
- The envelope (different types of façade and roofs, how to integrate solar panels etc.)
- Sustainable steel construction.

Figure 1.2 Office building in Paris

Illustration of the many opportunities for using steel in building construction can be found on the following web sites:

www.access-steel.com
www.acierconstruction.com (*in French*)
www.construiracier.fr (*in French*)
www.infosteel.be (*in French and Dutch*)
www.bouwenmetstaal.nl (*in Dutch*)
www.bauforumstahl.de (*in German*)
www.sbi.se (*in Swedish*)
www.szs.ch (*in French and German*)
www.apta.com.es (*in Spanish*)
www.promozioneacciaio.it (*in Italian*)
www.eurobuild-in-steel.com

There are several types of composite beams, as shown in Figure 4.7. In these examples, the steel profile can be a rolled profile, a welded profile or a cellular beam. In example (c), the steel profile is a rolled profile.



(a) Plain slab: this solution requires temporary formwork.

(b) A pre-slab or a steel decking is used as permanent formwork and contributes to the bending resistance of the slab.

(c) The beam is partially concrete encased to improve fire resistance.

Figure 4.7 Composite beams

In multi-storey buildings, the total depth of the floors often needs to be reduced to a minimum. The design of slim floors consists of integrating the steel beam to the concrete slab. Figure 4.8 shows two types of integrated steel beams.

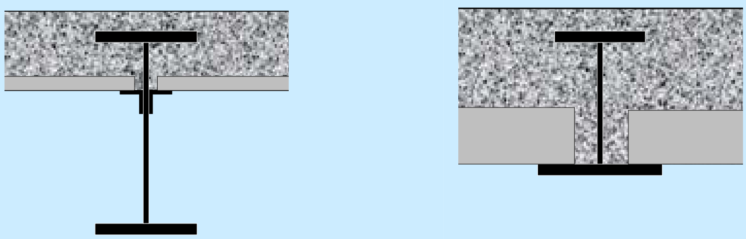
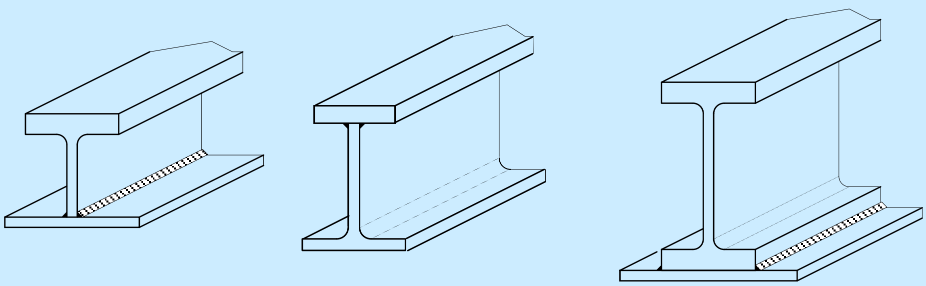


Figure 4.8 Integrated beams (slim floors)

Figure 4.9 shows three examples of steel beams used as integrated steel beams.



The lower flange is a plate welded to the web of a half rolled profile

The upper flange is a plate welded to the web of a half rolled profile

A plate is directly welded under the lower flange of a rolled profile

Figure 4.9 Different types of profiles used as integrated beams

The span ranges for the various structural options for floors are shown in Table 4.3.

Table 4.3 Span ranges of various structural options

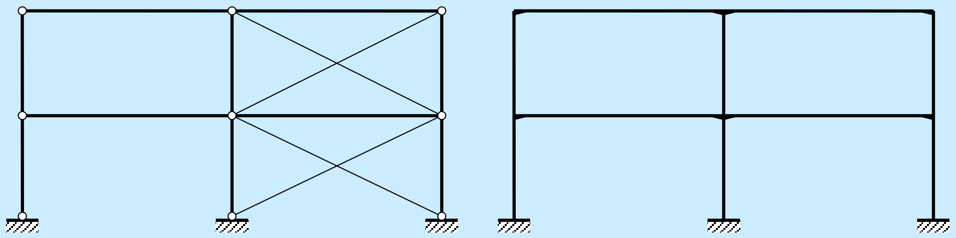
	Span (m)					
	6	8	10	13	16	20
Reinforced concrete flat slab						
Slim floor beams and deep composite slab						
Integrated beams with precast slabs						
Reinforced concrete beams and slab						
Post-tensioned concrete flat slab						
Composite beams and slab						
Fabricated beams with web openings						
Cellular composite beams						

4.2 Bracings

4.2.1 General

A structure is statically determinate when the number of supports is just enough to ensure its global stability. By increasing the number of supports and rigid connections, the structure becomes stiffer, but rigid connections are more expensive than simple connections. So an economic compromise has to be found.

Table 4.6 shows two options for the stability in a vertical plane of a multi-storey building.

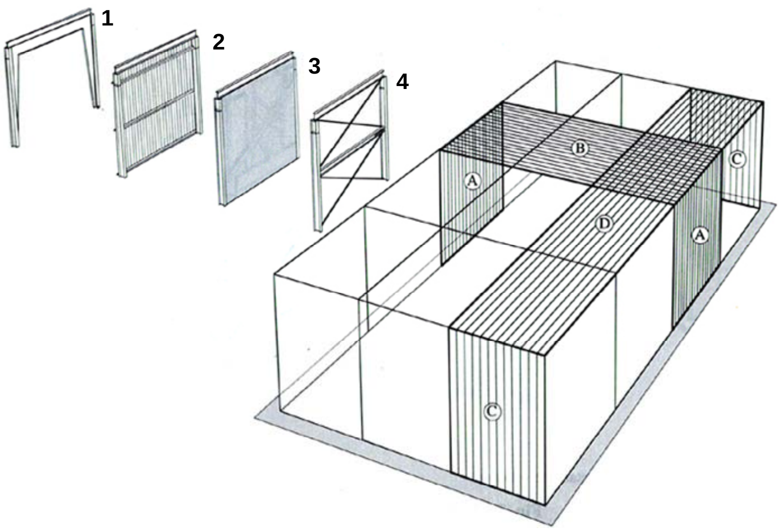


Braced structure
The global stability is ensured by cross bracing (see § 4.2.2). Simple connections are used. The bracing members in compression are generally ignored in the detailed design.

Frame effect
The global stability is ensured by frame effect (see § 4.2.3) thanks to the stiffness of the connections. This solution leads to more complex connections.

Figure 4.10 Global stability in vertical planes of a multi-storey structure

The stability of a building has to be ensured in all the main planes (vertical and horizontal planes) in order to transfer the forces to the foundations, as shown in Figure 4.11.



Key: - see text

Figure 4.11 Planes of stability for a rectangular building

The vertical stability (A and C in the Figure) can be provided by any of the four systems:

1 Cross-bracing (simple construction)
2 Frame effect
3 Diaphragm effect (contribution of the cladding)
4 Concrete wall.

The horizontal stability (B and D in Figure 4.11) is generally ensured either by the diaphragm effect in concrete floors or by a cross-bracing. Horizontal stability systems must be appropriately connected to vertical stability systems in order to transfer the forces to the foundations.

Wind action is the main horizontal action in multi-storey buildings. In seismic areas, horizontal actions due to earthquakes have to be considered.

4.2.2 Braced structure option

Multi-storey buildings are generally designed with pinned members. Vertical stability is commonly provided by cross-bracing, and sometimes by a concrete core. The advantages of such a design are:

- Simple connections
- Quick erection
- Reduced fabrication costs.

The cross-bracing can be either inside or outside the building, depending on architectural preference. An example of bracing as an architectural feature is shown in Figure 4.12.

Figure 4.12 External cross-bracing in a multi-storey building

4.2.3 Frame effect option

In order to avoid bracing between the beams, it is possible to design rigid-jointed continuous frames.

Multi-storey buildings with a load-bearing structure formed of rigid frames often require an increase in the column section and sometimes in the beam section.

Since ensuring stability by frame action is less economical than by bracing, a combination of the two systems can provide an efficient and balanced solution. It is possible to have frames in one direction and to use bracing for stability in the perpendicular direction.

The advantages of continuous frames are:

- The primary beams are stiffer – the deflections are lower than those of simply supported beams
- The floors are less sensitive to vibrations

Adding redundancy to the structure increases robustness.

The disadvantages are:

- The connections are more complex and the erection is more complicated
- The internal forces in the columns are increased

The structure is globally more expensive.

Structures made of continuous frames in both directions are exceptional. They can be recommended for buildings with special requirements (medical research, white rooms, equipment sensitive to deflections and vibrations, etc.).

4.3 Floors

4.3.1 General

The structural function of floors is to transfer loads to the main members of the structure. Floors also contribute to the global stability of the structure because they generally act as a diaphragm to provide stability in the horizontal plane of each storey.

The design of a floor conforms to specifications that include:

- Applied loads
- Thermal performance
- Acoustic performance
- Fire resistance
- Service integration
- Requirements to connect a false ceiling.

The structural part of the floor can be one of the following:

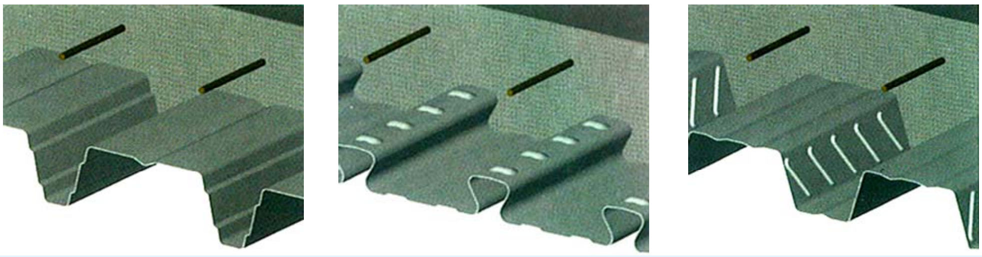
- Composite slab using steel decking
- Concrete slab with steel decking used as permanent formwork
- Dry floors
- Plain slab, concrete slab including a precast slab
- Prefabricated slab.

4.3.2 Concrete slab with steel decking

The use of steel decking has many advantages:

- Efficient permanent formwork (the formwork does not have to be removed after concreting)
- Installation of a steel decking is easier than that of a precast slab
- Propping during construction is often not necessary.

A simple steel decking is efficient as permanent formwork at the construction stage. Special steel deckings have been developed in order to contribute to the bending resistance of the floor, as a tension component. For these deckings, embossments provide a good connection with the concrete. See Figure 4.13.



Permanent formwork
(Non composite slab)

Composite slabs
(Steel deckings with embossments)

Figure 4.13 Concrete slab with steel decking

To optimize structural behaviour, a composite slab with steel decking can also be designed to contribute to the bending resistance of the beams (composite beams), as shown in Figure 4.14. This leads to a reduction in the size of the steel profiles, and subsequently in the total depth of the floor, the weight of the beam, etc.

Typical dimensions of a steel decking:

- Length: 6 m
- Width: 1 m
- Thickness: 0,75 or 1 mm.

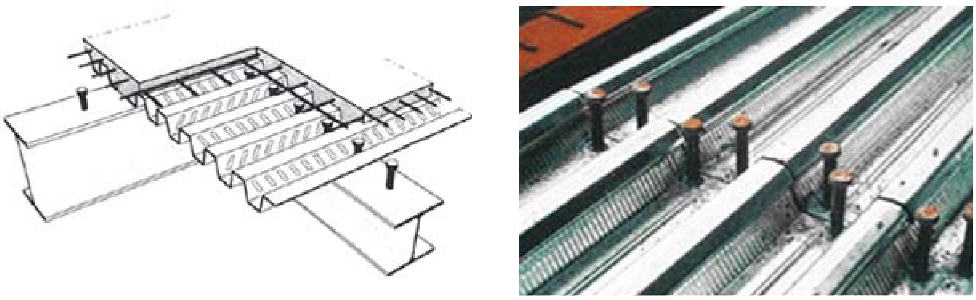


Figure 4.14 Composite slab and composite beams

Fire resistance of slabs composed of a steel decking and concrete

The steel decking has a mechanical function of reinforcement. The underside generally requires no protection. The composite slabs can have 30 minutes' fire resistance without special protection.

A higher resistance can easily be obtained by:

- Adding reinforcement bars in the slab
- Protecting the underside of the decking
- Adding a false ceiling of mineral wool and plasterboard.

4.3.3 Precast slab with in-situ topping

Plain slabs are generally composed of a precast slab and cast-in-situ concrete. At the concreting stage, temporary supports may be needed to transfer the weight of the precast slab, the concrete and operatives working on the site.

The slab can contribute to the bending resistance and stiffness of the beams if an appropriate connection (welded studs for instance) is provided between the slab and the beam – see composite beams in Table 4.3.

4.3.4 Hollow core slabs

Prefabricated hollow-core slabs are generally used with integrated floor beams (non composite beams). These elements can be placed on angles welded to the web or on the lower flange (see Figure 4.15, Figure 4.8 and Figure 4.9). A structural concrete topping with reinforcement is recommended in order to tie the units together to serve as a diaphragm component.

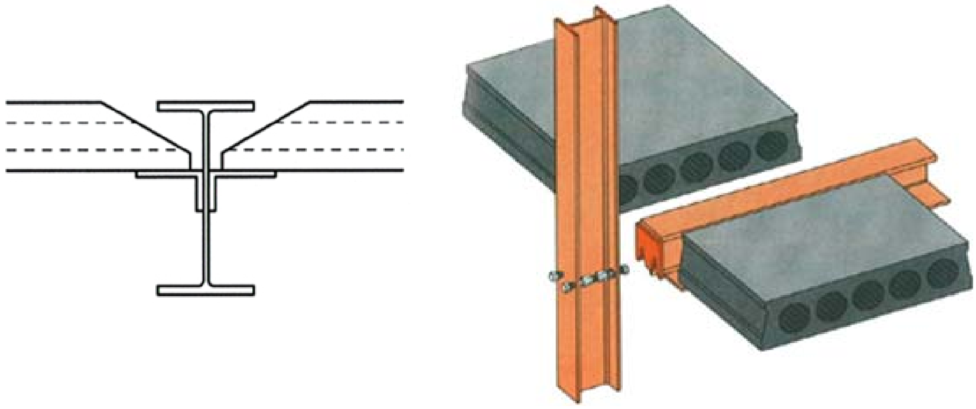


Figure 4.15 Hollow core slab

4.3.5 Prefabricated composite slab elements

This type of floor is manufactured in elements, the width of which is 1,20 m and the length up to 7,00 m as shown in Figure 4.16.

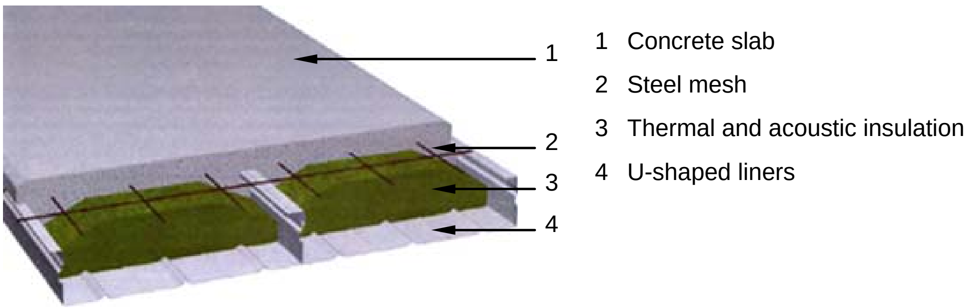


Figure 4.16 Prefabricated composite slab elements

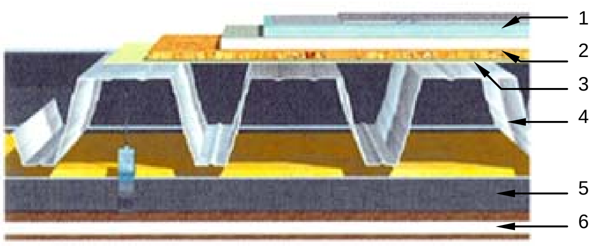
4.3.6 Dry floors

Dry floors are made of a mechanical assembly of industrialized components (see Figure 4.17). The main properties of dry floors are:

- Lightness
- Acoustic performance

- Thermal performance (insulation is integrated in the floor)
- Speed of erection
- No temporary propping during construction
- Flexibility.

The transfer of the loading is ensured by the profiled steel sheeting. Its length can vary between 2,00 and 6,00 m and its depth is about 20 cm. Services (cables, ducts) can be placed in the depth of the profiled steel sheeting. An electric heating film can be incorporated in the floor.



1 Two layers of plasterboard
2 Wood board
3 Resilient material
4 Profiled steel sheeting
5 Layers of mineral wool
6 1 or 2 layers of plasterboard

Figure 4.17 Main components of a dry floor

Figure 4.18 Photo of a dry floor

The fire resistance of a dry floor depends on the fire performance of the false ceiling and the upper components made of plasterboard. Performance can be adapted to national regulation or other specific requirements.

4.3.7 Acoustic and thermal requirements for floors

In order to fulfil requirements relating to acoustic and thermal insulation, other materials can be connected to the slab. Such materials also provide an appropriate facing.

Such elements are:

- Plasterboard connected under the composite floor, the number layers of which depends on the required acoustic performance

- Mineral wool layers supporting the plasterboard.

The space between the beams under the floor can be used for service integration (ducts).

Figure 4.19 Composite slab with thermal insulation

4.4 Connections

4.4.1 General

Steel construction is based on a simple principle, involving the assembly of elements, such as columns, beams, bracing members, tie members. The components of the building envelope – floors and partitions – are then connected to the principal members.

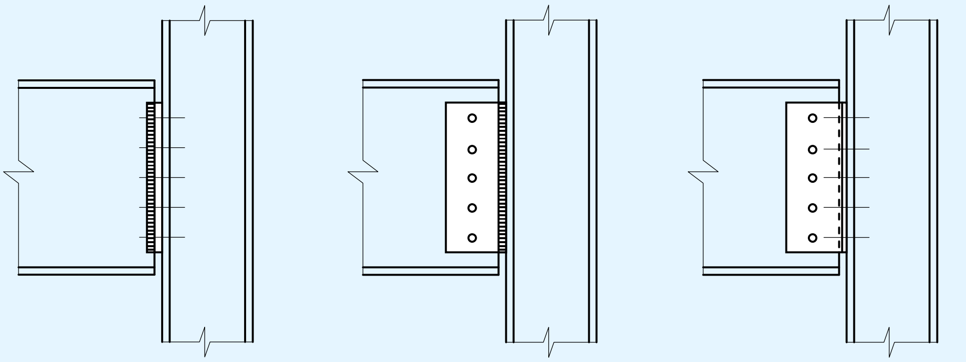
The main function of a connection is to transfer internal forces between the members, in a way that is consistent with the design assumptions – pinned or continuous connection. When the connections are visible, their aesthetic quality can emphasise the structural behaviour and contribute to the architectural value of the building

4.4.2 Types of connections

There are many types of connections for structural members. The principal types commonly used in multi-storey buildings are:

- Nominally pinned connections (beam-to-beam and beam-to-column)
- Moment connections (beam-to-column) for continuous frames
- Connections of bracing members
- Column bases.

Figure 4.20 shows three types of beam-to-column connections. These connections can be considered as pinned. This type of connection is mainly designed to transfer a shear force and a small axial force.



End plate welded to the web of the beam and bolted to the column flange

Fin plate welded to the column flange and bolted to the web of the beam

Double angle web cleats: angles bolted to the column flange and the beam web

Figure 4.20 Typical beam-to-column connections – pinned connections

Figure 4.21 shows the connection of a secondary beam to a primary beam using double angle web cleats. The secondary beam is notched so that its top flange is at the same level as the top flange of the primary beam.

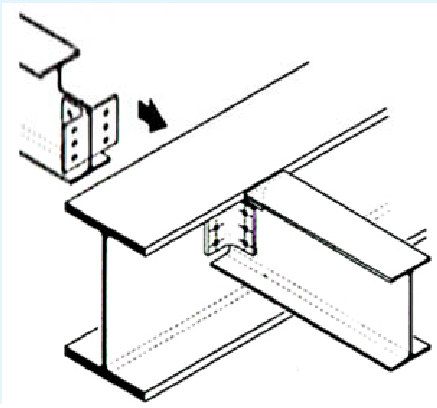


Figure 4.21: Typical beam-to-beam connection

Figure 4.22 shows an example of rigid beam-to-column connection. The end plate is welded to the beam and bolted to the column flange. This type of connection is designed to transfer a bending moment and a shear force.

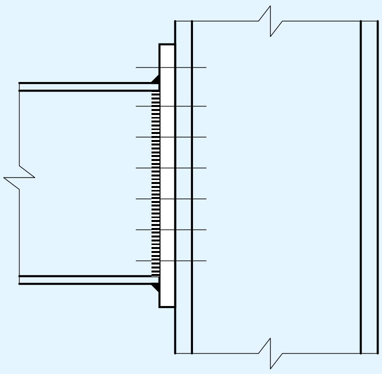
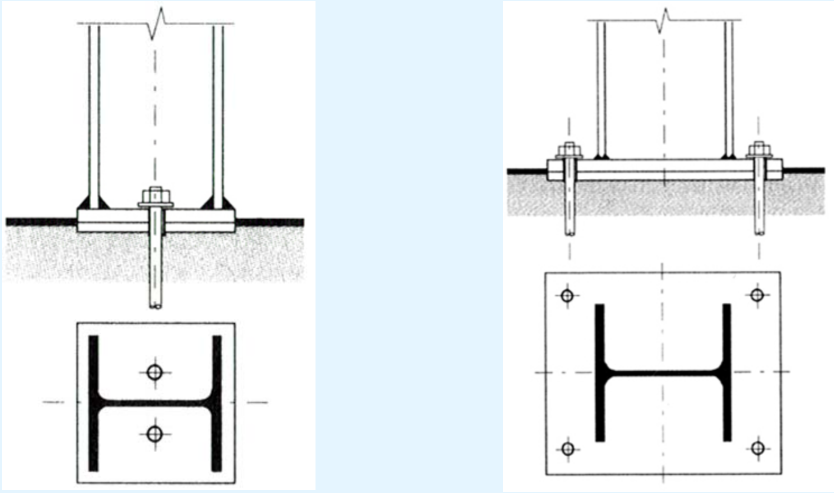


Figure 4.22 Moment connection

In multi-storey buildings, the column bases are generally nominally pinned, such as that shown in Figure 4.23(a). Significant compression force is transferred to the concrete foundation. In routine situations, the shear force remains quite low. Figure 4.23(b) is a fixed column base, shown here by way of comparison.



(a) Pinned column base (b) Fixed column base

Figure 4.23 Column bases

The ends of bracing members are usually bolted onto gusset plates. The gusset plates can be bolted, or sometimes welded, to the main members (beam and column). An example is shown in Figure 4.24

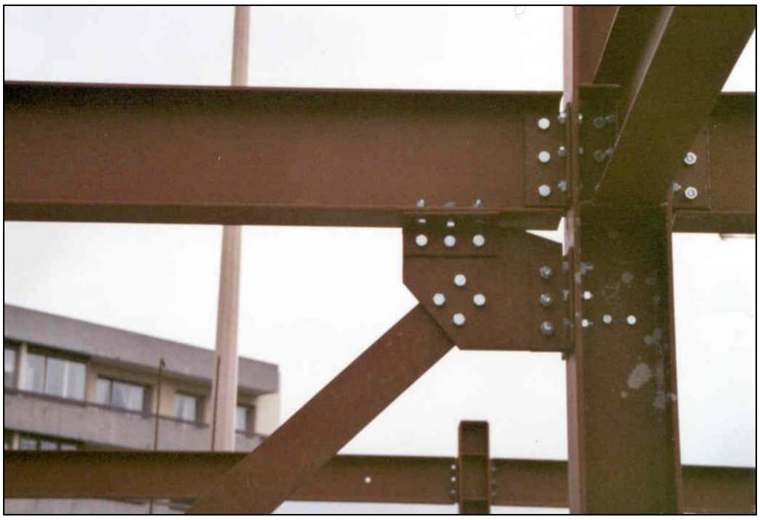


Figure 4.24 Typical connection of a bracing member

4.5 Summary

Table 4.4 gives typical weights of building elements.

Table 4.4 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
Plain slab (Normal weight concrete, 200 mm thick)	5 kN/m^2
Composite slab (Normal weight concrete, 130 mm thick)	2,6 to 3,2 kN/m^2
Composite slab (Lightweight 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

Steel provides many advantages to the architect for the design of a multi-storey building:

- Large spans are possible
- A steel building is lighter than a traditional building
- The foundations are simple and less expensive
- This solution is well adapted to soils with poor load-bearing qualities.

5 BASIS OF GOOD DESIGN: THE ENVELOPE

5.1 Façades

5.1.1 General remarks

When steel is the material of choice for construction, façades are made up of a series of fabricated products which fulfil the following functions: load-bearing capacity, air tightness, water tightness, protection against intrusion, thermal and acoustic insulation, fire protection and, of course, aesthetic appearance.

Application of these products for façade systems guarantees a high level of precision and performance and therefore demands a certain degree of design rigour, particularly in the connection and cladding details of the various components.

With its component elements, the steel in a façade can be used for secondary frames (light steel elements or double skin façade with steel sheeting or trays), support for external facing, cladding and, lastly, for decoration and solar protection.

Steel construction solutions can also be combined with other types of façade facing: steel cladding, stone, brick, terracotta, wood and glass (see examples in Figure 5.1). They offer a true palette of architectural solutions in terms of appearance, shape and finish.

The huge range of façade dressings can influence performance and provide solutions for all types of project (Figure 5.2), including:

- Public amenities
- Offices
- Apartments and hotels
- Commercial buildings.

Steel cladding – Montargis (France)

Steel cladding – Montargis (France)

Terra Cotta – Fulham (United Kingdom)

Stone – Bagnolet (France)

Wood– Luxembourg (Luxembourg)

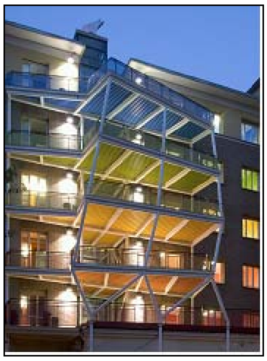
Render on load-bearing walls – Helsinki (Finland)

Figure 5.1 Types of material for façades

Millenaris – Budapest (Hungary)

European Parliament (France)

House buildings - Evreux (France)

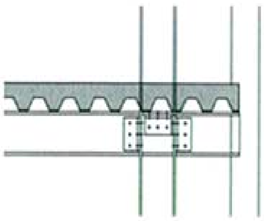


University – Torino (Italy)

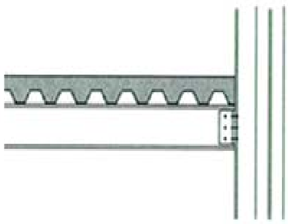
Figure 5.2 Façades for various types of project

5.1.2 Positioning the façade

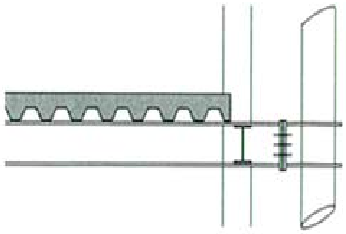
There are three configurations for positioning the façade in relation to the structure, as shown in Figure 5.3.



EXTERNAL: curtain wall, prefabricated wall panels



DOUBLE FAÇADE: infill light walls and external cladding



INTERNAL: panel walls façade

Spinningfield office
Manchester

Royal northern college of music
Manchester

Industrial workshops for public transportation company - Paris

Figure 5.3 Positioning the façade

The features of these three options are:

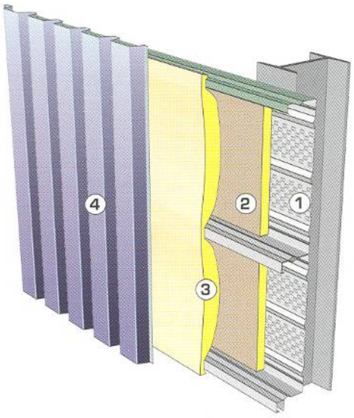
- A completely external façade: the structure is visible inside
  - The façade is a series of panels installed between floors
  - If the column is hidden, the most cost efficient section should be used
  - If the column is visible, the aesthetic appearance will need to be considered.
  - In this case, fire protection requirements vary according to the building use and there are numerous solutions to satisfy these (see 6.2.4).
- A double façade thickness:
  - Generally speaking, and since the column is not visible, the most economic solution will be determined by the choice of section.
  - If sizing leads to a discontinuity in the façade facing, the columns can be divided into two in order to reduce obstruction.
  - Internal and external facings which have been adapted will ensure structural fire protection.
- Internal façade: the structure is visible outside the building
  - The façade beam connection must be examined carefully, especially in terms of thermal, structural and fire protection needs. Special arrangements can be put in place.

5.1.3 The construction principle

In most construction elements for lightweight façades, the edge of the floor is used to determine the limit. The vertical plane it defines is for fixing elements, for reducing thermal bridging and for fire protection between floor levels.

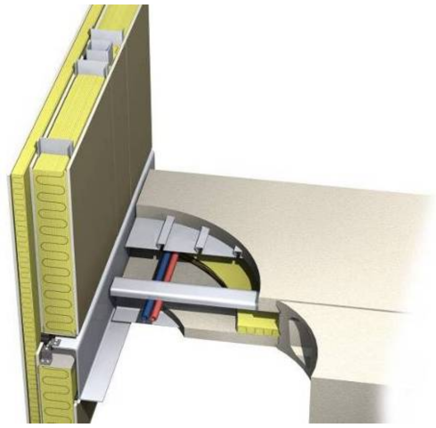
On the outside, are the support elements for the external facing (secondary frames, plates), which are installed vertically or sometimes horizontally. A primary layer of thermal insulation is then applied. The external facing is placed on this frame using a fixing device (transverse frame, bracing, pre-frame, etc.). The external facing can be fabricated panels with insulation (Figure 5.4).

On the inside, a double-skinned partition, comprising between one and three layers of plasterboard fixed to a light steel frame, is commonly used. Additional insulation is applied between the frame posts (Figure 5.5).



Example of Vertical cladding

1 Internal cladding – support for the façade
2 Thermal or acoustic insulation (1st layer)
3 Thermal insulation – 2nd layer behind steel trays
4 External cladding



Pre-fabricated large wall panel with integral SHS sections (Finland)

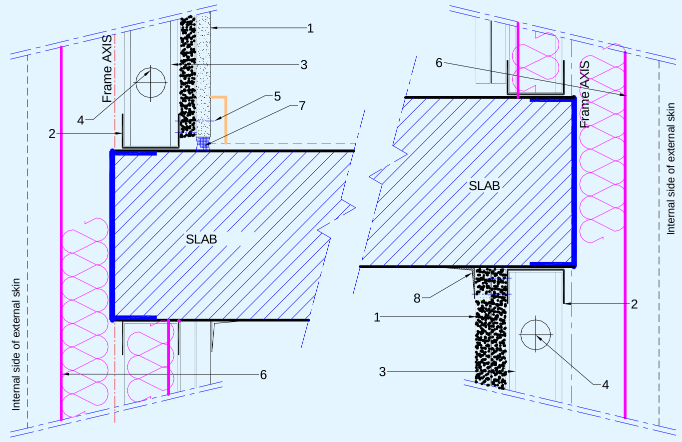
Figure 5.4 Cladding

Figure 5.5 Thermal insulation

These lightweight façade systems often contain an air space for ventilation between the continuous insulation layer applied in front of the floor edge and the internal side of the outer facing.

This arrangement is conducive to good hygrothermal performance of the partition wall and facilitates installation of unjointed facing elements. However, installation of a rain screen to protect the external insulation layer is essential.

If the external facing is watertight, the air space cannot be introduced and the façade will not be ventilated.



Detail for bottom of infill walls

Detail for top of infill walls

A Slab
B Frame axis
C Ventilated air layer
D Internal side of external skin

1 Gypsum board
2 Light steel gauge rail
3 Light steel gauge post
4 Hole for services

5 Screw
6 Steel frame
7 Air barrier
8 Joint treatment

Figure 5.6 Infill walls

5.1.4 Thermal and acoustic elements

Thanks to the two insulation layers, it is possible to vary the type (mineral wool, polyurethane, cellular glass) and the thickness of materials used and thus to eliminate a substantial amount of thermal bridging. The risk of direct heat transfer (cold bridging) must be treated at the level of the fixings and joints between the metal parts which are in contact with internal spaces and external areas.

Acoustic performance also depends on the system and fixing of the external cladding and the insulation density. To improve comfort, the internal finish facing material can also consist of perforated metal sheets (see Figure 5.4), allowing the mineral wool insulation material in the façade to correct the acoustic performance through atmospheric absorption at a high sound pressure level.

Lightweight façade solutions using steel structures are ideally suited to new construction and also to refurbishment and in particular to upward building extensions.

University of technology, Rzeszow (Poland)

Residential building (Denmark)

Figure 5.7 Refurbishment and extensions

Table 5.1 Comparative weights of façades and partitions

Type of façade	Weight (kg/m^2)
Heavy façade: - Bearing wall of 18 cm - 8 cm outside insulation - Terracotta or stone facing 20 to 50 cm	80-100 (wall not included)
Light façade: - Secondary frame of façade (cold-formed profiles) - A layer of mineral wool - Partition of dubbing of 0,07 cm - Outside finish facing - steel tray	30-50
Concrete wall of 20 cm	500
2 H-shaped columns of 0,20 m 1 I-shaped beam of 0,27 m Light partitions of 0,20 m	30-50 depending on the use

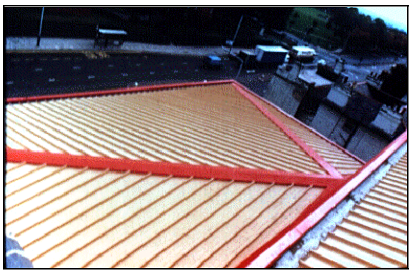
5.2 Roofing systems

5.2.1 General remarks

Steel frames can accommodate all types of roofs, from watertight roofs to flat or arched roofs, as well as opaque or glass roofs.

SuperC building – Aachen

Stone – Bagnolet



Wood– Luxembourg

Pitched roof on site

Glass roof

Figure 5.8 Roofs

The building envelope needs to respond to many different requirements, see Figure 5.9.

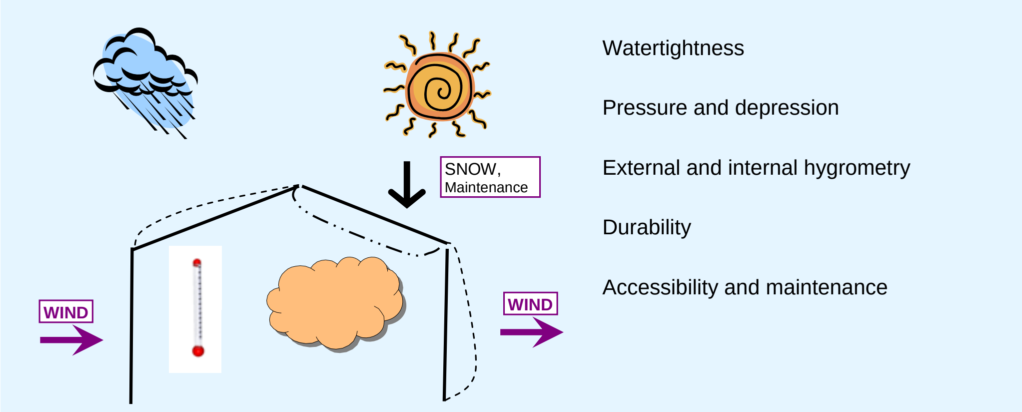


Figure 5.9 Requirements for building envelope

Roof typology depends on several criteria, including shape, roof slope, external appearance, material colour, type of support and the materials used.

Roofs are usually divided into three types:

- Flat roofs with no slope
- Pitched roofs (slope between 3 and 7%)
- Steep or arched roofs

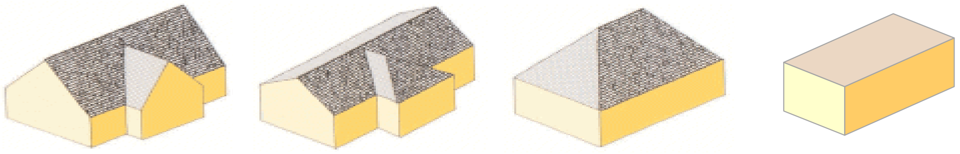


Figure 5.10 Roofs

For low slope roofs, the most important elements for the steel frame are the quality of fixings and arrangements for rainwater evacuation (Figure 5.11).

5.2.2 Flat roofs

The principle of flat roofing systems on surface support elements can be applied using lightweight partitions, a metal sheet (see Figure 5.12) or the concrete topping technique with a concrete compression decking.

A vapour screen, thermal insulation and waterproofing, with or without protection, are installed on the upper side. In order to provide the parapet which will be used to increase water tightness, it is possible to use a secondary steelwork façade which can be en extended to the required height.

5.2.3 Pitched roofs

In the case of a low pitch roof (slope between 3 and 7%), water tightness is also obtained by applying bituminous products or PVC watertight membranes. Insulation is applied directly to the galvanized steel sheet tray. The process is light and economical for non-accessible roofs. Phonic insulation is adjusted through thickness of the materials and the order in which these are superimposed.

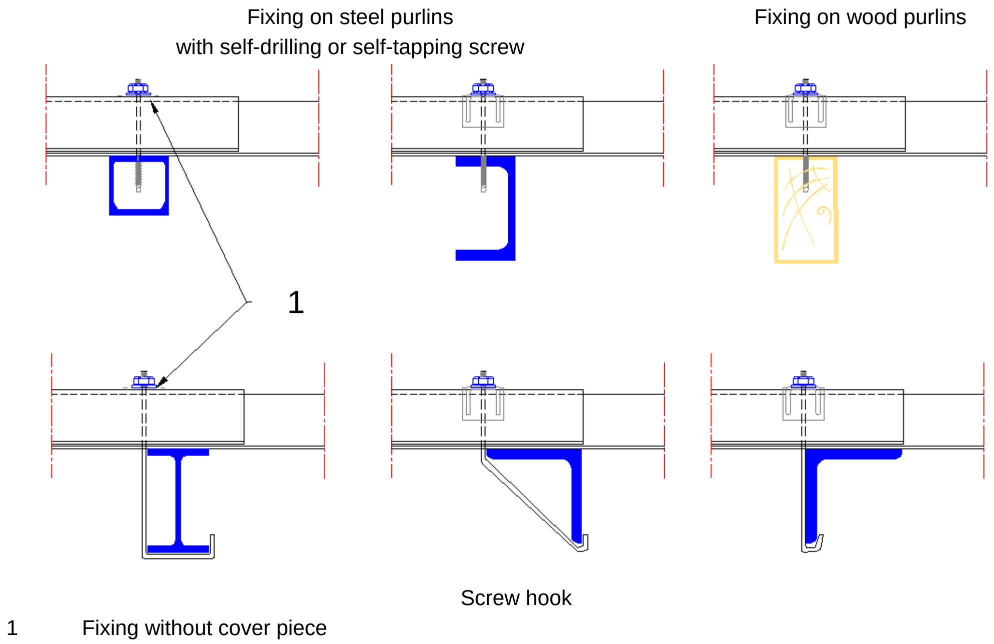
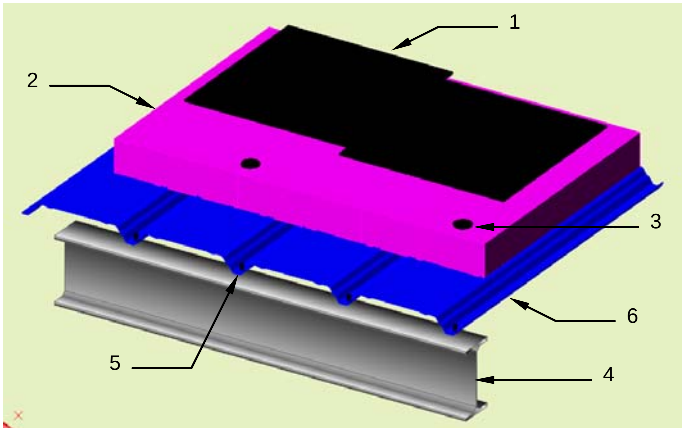


Figure 5.11 Types of fixings



1 Sealant coating
2 Rigid insulation
3 Insulation connection
4 Steel sheet
5 Screw on beam
6 Beam

Figure 5.12 Typical view of a flat roof

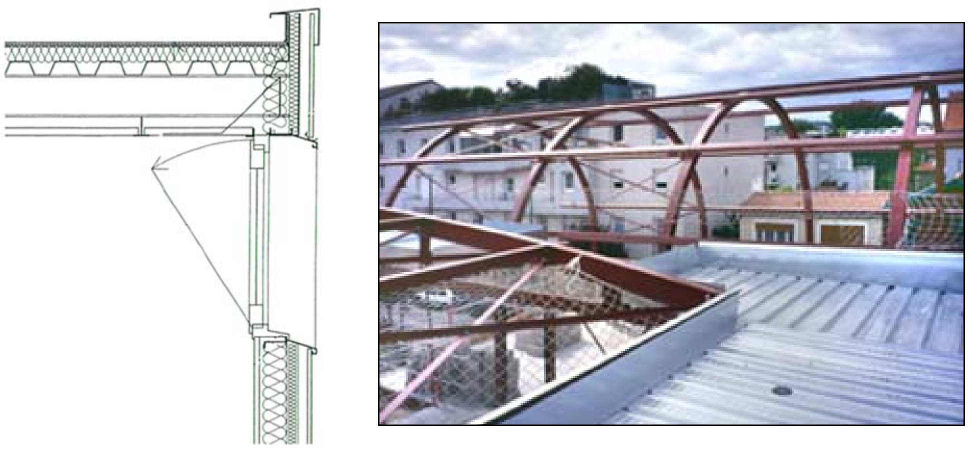


Figure 5.13 Corner of façade and roof – On site view

5.2.4 Steep or arched roofs

Water tightness is easily obtained by overlapping of the metal sheets, more or less following the roof slope and the product. The most common procedure is to superimpose materials so that all air space is eliminated.

Figure 5.14 Curved roof

5.2.5 Roof construction

A typical roof construction, from the exterior inwards, consists of:

- A ribbed steel decking fixed perpendicular to the panels
- A primary layer of insulation made of a taut felt sheet combined with an internal vapour screen placed between the decking and panels
- A second and thicker layer of mineral wool
- A steel frame on which to fix the product which is used for the internal finish
- A second vapour screen
- An internal finish facing material, of one or two layers of plasterboard screwed to the steel frame or, in some cases, steel decking or perforated steel decking.
- Acoustic insulation to control rain noise is particularly effective.

Roof netting systems with different amounts of perforation can be fixed on metal roofs to handle thermal shock and to improve the architectural concept using a canopy.

Galvanized steel sheets, whether pre-painted or not, and stainless sheets, are particularly suitable for arched roofs (see Figure 5.15). Stiffening ribs improve bending strength.

The plates are supported by panels, the characteristics of which determine the spacing and loads to be carried. Fixing is carried out above the stiffening ribs, using compressed watertight joints.

Figure 5.15 Curved roof with galvanized steel sheet

5.2.6 Renewable energy systems

The roof can be designed to accommodate various systems for renewable energy, such as solar panels. Figure 5.16 shows photovoltaic panels on a residential building.

© SYSTAIC

Figure 5.16 Photovoltaic panels installed on a roof

Figure 5.17 shows wind turbines with vertical axis installed on a flat roof.

www.innoenergie.com

Figure 5.17 Array of small-scale vertical axis wind turbines on a flat roof

6 OTHER FACTORS FOR GOOD DESIGN

In addition to the benefits described in previous Sections, which were concerned with mechanical performance and technical application, steel offers:

- Savings in structural weight
- Optimized space and return on investment
- Clean and efficient construction sites.

Good practice in steel building design and the appropriate choice of materials, mean all the following requirements can be met, whether regulatory or at the client's request:

- Seismic behaviour
- Fire resistance
- Acoustic performance
- Thermal performance
- Sustainability
- Service integration.

6.1 Behaviour during an earthquake

Steel structures are particularly well suited to construction in earthquake zones. This is mainly due to reduced accelerated mass, as well as the high ductility of steel material that allows significant energy dissipation.

Good seismic performance of steel structures is demonstrated by the fact that destruction of steel buildings due to earthquakes in any part of the world is rare. The most recent analysis of the consequences of a major earthquake in Europe confirms this fact. On April 6, 2009, a magnitude 6.3 earthquake struck close to the city of L'Aquila, located approximately 90 km north-east of Rome. Steel structures in the region affected by the earthquake were mainly industrial or commercial buildings, located outside towns. These structures suffered very little damage. Any minor damage recorded did not affect their structural integrity and there was a rapid resumption of activity. The photographs in Figure 6.1, taken in the days that followed the earthquake, show the commercial centre of Aquilone.

It is worth highlighting that the centre for emergency relief was set up in the gymnasium of L'Aquila. This steel building, which consists of circular columns and a three-dimensional truss roof, provided a huge empty space and it was possible to continue to use it despite the many aftershocks in the weeks following the main earthquake. The Italian authorities have every confidence in the seismic behaviour of this type of building.

Figure 6.1 Commercial centre of Aquilone

6.2 Behaviour during a fire

6.2.1 General remarks

Requirements in terms of structural behaviour during a fire are defined in national regulations. These depend on the end-use of the building, its size and accessibility, and the consequences in the event of collapse.

The objectives of fire safety objectives are:

- To ensure stability of the load-bearing elements for a specified period of time
- To limit the emergence and spread of fire and smoke
- To facilitate rescue operations
- To facilitate safe and rapid evacuation of occupants
- To limit the spread of fire to neighbouring structures.

To achieve these objectives, regulations impose different types of requirement:

- Requirements relating to materials: reaction to fire
- Requirements for building elements (principal structural and secondary non-structural elements): fire resistance, enhanced by passive protection
- Requirements related to layout of access and measures for active protection.

It is essential to take account of these requirements from the initial stages of design. To consider fire protection requirements as an afterthought could result in significant costs or even call into question the actual design.

6.2.2 Reaction to fire

Certain materials can speed up the development of fire. Table 6.1 gives the European classifications for reaction to fire of building materials. Steel, a non-combustible material, is classified as A1.

Table 6.1 European classification for building materials

Class		Comment
A1	non-combustible products	No contribution, even in highly developed fire. Must automatically satisfy other less stringent classes
A2	non-combustible and not very combustible products	Class B + little contribution to fire load and to development of fire in event of very developed fire
B	combustible products	Item C with even stricter criteria
C	combustible products	Item D with stricter criteria
D	combustible products	Product resisting attack of small flame for longer period. Capable of undergoing thermal attack from isolated object on fire with delayed and limited heat release
E	combustible products	Products capable of resisting attack by small flame without substantial spread
F	unclassified products	No fire reaction performance defined

The system provides additional classifications, as given in Table 6.2.

Table 6.2 Additional classes

Production of inflamed smoke		Production of droplets or debris	
S1	low smoke production	d0	absence of inflamed droplets
S2	medium smoke production	d1	no inflamed droplets exceeding 10 seconds
S3	no limit required	d2	inflamed droplets (persistence > 10 seconds)

6.2.3 Fire resistance

Resistance to fire is the ability of a building element to continue to perform its intended function in fire.

The fire resistance classification of a building element is defined by:

- Standardized criteria (see Table 6.3)
- Degree of fire resistance (duration, expressed in minutes, before reaching criteria)

It measures the fire performance of the classified element.

Requirements for fire resistance of building elements are expressed in terms of a classification criterion and a time for which the criterion must be satisfied.

Table 6.3 Classification for building elements

Criteria	Definitions
R	**Mechanical resistance**: ability to resist thermal attack from fire without loss of structural stability
E	**Air tightness in a fire**: ability to prevent spread of flames and hot gases
I	**Thermal insulation**: ability to prevent increase in temperature of side not exposed to fire
W	**Thermal radiation**: ability not to emit thermal radiation greater than 15 kW/m^2

The classification of a construction element may be:

R, RE, E, REI or EI, followed by the time in minutes -15, 30, 60, 90, 120 minutes, etc.

Additional criteria and criteria specific to certain facilities are also given - see Table 6.4.

Table 6.4 Additional and specific criteria

Criteria	Additional criteria
S	**Air tightness to cold smoke:** Prevents propagation of smoke in fire, even if relatively cold
C	**Automatic shut down:** Door, valve or shutter closes automatically
M	**Resistance to impact:** Vertical partition to resist lateral mechanical shock

Criteria	Specific criteria
B_0	**Outlet ducts for smoke (30 min):** Outlet duct removes hot gases during the first 30 minutes
D	**Barriers (30 min):** Confine hot gases and smoke during initial 30 minutes
F_θ	**Smoke vents (30 min):** Remove hot gases and smoke during initial 30 minutes

Tests or calculations are needed to demonstrate or justify the fire performance of a building element or product. Tests are defined by standards which define the methods and experiments to be undertaken for a specific type of behaviour.

Calculations can be based on conventional approaches (constant increase in temperature over time), or on the new approach to fire safety engineering introduced by the Eurocodes, through advances in knowledge about the behaviour and development of fire.

6.2.4 Passive fire protection methods

As with other materials, the strength and stiffness of steel decrease at elevated temperatures.

Conventional fire resistance of an unprotected steel section rarely exceeds 30 minutes when subjected to normal levels of loading.

Passive fire protection is therefore used to slow down the heating of steel structures in order to give the required fire resistance.

A number of systems are available: these are listed below. They provide the steel structure with the appropriate levels of protection, regardless of building end-use. They are sometimes combined.

Screen protection

Screen protection isolates the structure from an advancing fire by the interposition of elements that form a continuous wall. In a vertical position they serve as wall panels; when horizontal, they are suspended ceilings. All products used must have been tested for fire resistance.

The screen should be chosen for its fire resistance properties and can be used for acoustic and thermal insulation, as well as for aesthetic reasons.

Spray applied fire protection

This is the most common form of protection. There are two basic sorts of product, thick film and thin film.

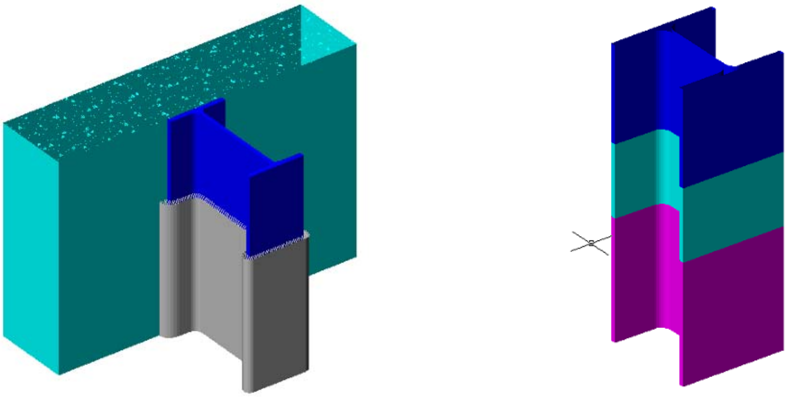


Figure 6.2 Fire protection

With thick film coatings, the spray product or coating is fibrous or paste-like. It is generally composed of mineral fibres, vermiculite, slag or gypsum, together with a binder. It is sprayed on with special equipment under wet conditions. Several layers may be necessary, which increases the drying time.

Fire protection can last up to 4 hours.

Thin film coatings, called intumescent coatings, have a special property - they swell heat. When cold, the film thickness is between 0.5 and 4 mm. When heated to a temperature between 100° C and 200° C, the film swells and turns into foam, reaching thicknesses of 30 to 40 mm; this protects the steel element.

These paints are applied with a spray or brush and careful application of the products ensures that protection is uniform.

Conserving the aesthetic appearance of the steel is the main advantage in this type of protection, which can last up to 120 minutes.

Board protection

Board protection is achieved by forming a casing around the steel element. This is done with mechanical fasteners (screws, staples) or adhesive. The boards are made of gypsum, vermiculite, mineral fibre or calcium silicate compounds.

The principle consists in.

The passage of hot gases into the joints is a risk and requires special attention during application. This solution must be very carefully applied.

Performance may reach R120.

Composite steel-concrete construction

In composite construction, the combined properties of steel and concrete can increase the fire resistance to cold and fire.

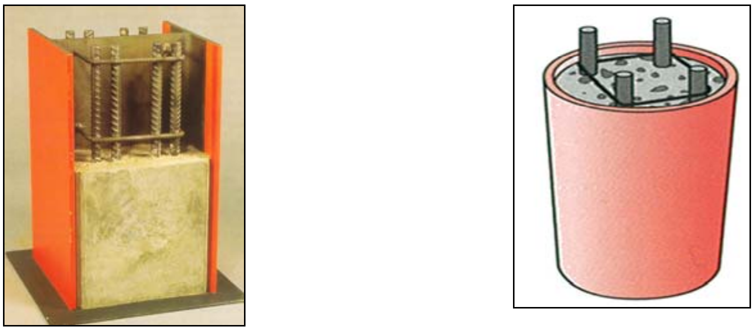


Figure 6.3 Composite construction

For I or H columns, the composite section consists of a complete coating, or more often a filling, between the web and flange, as shown here.

For tubular columns, the section is rendered composite by filling the tube with concrete.

The weight of the columns is significantly increased, but the performance can achieve a resistance of R180. Composite steel-concrete design is also effective in providing the floor beams with significant fire resistance.

Placing structure outside the envelope

An external structure is only exposed to flames projecting from openings and from burning parts of the building. Contact with the ambient air also helps to cool it down.

Positioning the structure outside the building can avoid the need for fire protection.

6.2.5 Active fire protection methods

When dynamic fire protection devices are used (detection, alarms, smoke extraction, sprinklers) or if there is human intervention to put out the start of a fire (extinguishers), these are called 'active' methods.

Figure 6.4 Active fire protection methods

Their main purpose is to limit the spread of fire, in order to allow people to escape as quickly as possible and to facilitate the prompt intervention of the emergency services.

Detection systems

Fire detection requires different types of devices that are characterised by the processes they use (static, velocimetric or differential), the phenomena detected (smoke, flames, heat, gas) and the sphere of activity (confined or linear).

Table 6.5 Main type of detectors

Detectors	Function	Application domain
Ionic	Comparison between ambient air and air contained in exposed room	Offices, circulation areas
Smoke	Abatement or diffusion of light through smoke	Computing areas or areas prone to smoke
Flames	Optical system, sensitive to infrared or ultraviolet light)	Storage of inflammable liquids or electrogen group
Thermal	Sensitive to heat	Aggressive areas (in combination with other forms of protection)
Thermal velocimetric	Sensitive to rapid increase in temperature	Aggressive areas (installation near sources of normal heat)

Autonomous Detection and Release systems (ADR) also exist. After detecting a local phenomenon linked to fire, one or more Activated Safety Devices (ASD) are released; the purpose is to activate the safety equipment: fire door, smoke extractor, etc.

Extinguishers and smoke extraction systems

Extinguishing systems commonly applied in warehouses create a foam blanket, the effect of which is to reduce oxygen and/or to cool down the premises.

Automatic water fire extinguishers (sprinklers) are designed to detect fire by means of thermo-sensitive sprinkler heads.

Gas extinguishers using CO_2, FM200, Novec or other gases which rely on the principle of CO_2 reduction in the area subject to fire. This process is often used in computer offices, white rooms/laboratories or hospital theatres), etc.

Outlet ducts are used to evacuate smoke and hot gases in order to allow people to escape and to limit increase in temperature of the premises. These come in various types of openings (single or double doors with intumescent strips), which are placed on the roof or façades and can be released manually with fuses or using an ADR.

Figure 6.5 Smoke extractor

6.2.6 Other requirements

National regulations also define requirements for:

- Facilitating evacuation of occupants (number and size of exits)
- Protection of individuals (containment of fire, confinement of smoke and smoke evacuation, emergency exits, legibility of escape routes, duration of building stability for evacuation purposes)
- Response by emergency services (access to building, safety standards, training).

6.3 Acoustic performance

6.3.1 General remarks

In order to ensure an acceptable degree of acoustic comfort, national regulations draw up requirements in accordance with building end-use.

The occupants of a building must be protected from different noises:

- Airborne noise: vibrations which begin in the air.

  This is the sound of voices or internal and airborne ambient noise, or road traffic as external airborne noise
- Structure-borne noise: resulting from shock and solid-borne vibrations.

  These are the sounds of footsteps, fallen objects, impact.
- Noise from equipment: generated by the operation of equipment, these are air-borne vibrations emitted through their media.

  These are the sounds of ventilation, heating, sanitary appliances.

The transmission of noise from the outside to a room, or from one room to another, occurs through vibration. This can be distinguished as:

- Direct transmission: through the wall which separates the receiving from the originating area.
- Lateral transfer: through the walls which are connected to the partitioning wall
- Parasitic transmissions: these result from single points in the partition wall (air intakes, ducts or installation defects).

Acoustic insulation provided by a partition lies in its ability to resist the transmission of sound from one side to the other. The sound reduction index is used to measure the performance of the wall. This is expressed in dB.

Regulations set minimum values for this index as a function of the building end-use, of the type of facilities being separated and for the airborne sound, impact sound and equipment noise.

It should be noted that the insulation provided by a real wall is always less than the index measured in the laboratory, because of lateral transfer and parasitic resonance.

The acoustic behaviour of a wall is illustrated by applying the mass-spring-mass law:

- The acoustic reduction index increases with the surface density of the wall
- For a double skin wall (two sandwich panels), this index depends on:
  - Mass per unit area of each partition
  - Thickness of the air space between partitions
  - Thickness of acoustic absorption
  - Critical frequency of each partition

The index of a double skin wall is much greater than a single wall with the same surface density. (The sound emitted from a room and spreading to another room horizontally and vertically passes through first layer of products which causes an initial reduction. It is then 'trapped' in the central void of the wall, where it bounces against the second partition and is absorbed by the insulation layer before returning residually through the second partition wall).

The acoustic performance of a steel building depends on the composition of the various partitions: external and internal, vertical and horizontal. Construction solutions are available which can achieve the very highest levels of performance.

6.3.2 Partitioning

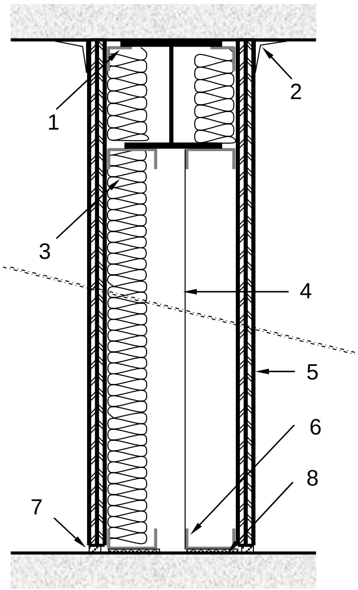
Partitioning usually consists of thin, cold formed steel elements on which plasterboard sheets of varying thicknesses are screwed onto both sides. This creates a central air cavity in which one or more layers of insulating mineral wool are inserted.

It can incorporate the main structural building elements.

The composition of a partition wall can be adapted to the required level of performance by varying the following parameters:

- Thickness of the air cavity: the more this increases, the higher the acoustic performance; the size of the main structural elements governs the choice of thickness
- Composition of each facing (number and type of plates finished in plaster)

- Partition frame: use of a double metal stud wall separate from the building improves performance
- Absorbent pad: the type and thickness of the insulation affects its quality.



Installation of a resilient joint under the panel rail of each frame is strongly recommended.

1	Angle	5	Plaster board
2	Seal	6	Rail (70 mm)
3	Mineral wool	7	Air-tightness seal
4	Upright 70 (independent double frame)	8	Closed cells moss

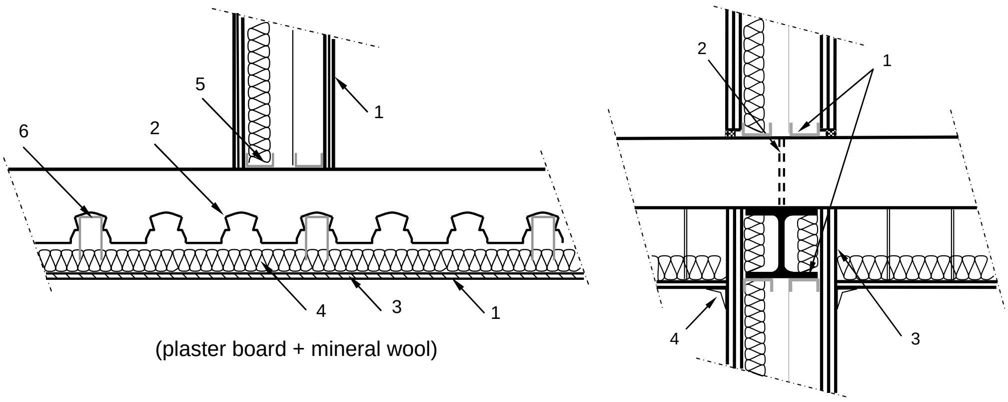
Figure 6.6 Double skin partition

6.3.3 Floors

In steel framed multi-storey buildings, the composition of the floors is completed with the installation of steel sheeted plasterboard to improve acoustic performance. This can be adapted for all types of floors: concrete decks, cellular structures, composite floors, etc.

Several parameters influence acoustic performance:

- Thickness of the concrete deck
- Depth of the ceiling void under the slab (minimum 60 mm, maximum 100 mm)
- Type and number of plasterboard sheets (1 or 2 standard or special sheets)
- Type of absorbent mattress placed between the false ceiling and the slab.



1	Plaster board	4	Mineral wool
2	Steel sheet	5	Rail 70 mm
3	Plaster board	6	Fixing

1	Resilient strips under rail
2	Gap if slab depth < 15 cm
3	Ceiling void interrupted by the partition
4	Seal

Figure 6.7 Cross sections on floor

Particular attention should be paid to the control of horizontal transmission:

- Depending on the thickness of the slab, it may be necessary to make a cut in the slab perpendicular to the partition walls.
- For the same reason, the ceiling void formed above the false ceiling must be interrupted perpendicular to the partition walls.

Finally, at the bottom of the walls, holes for technical equipment must not be drilled opposite one another (minimum spacing of 50 cm)

Figure 6.8 On site supplies with installation of plasterboards – Partitions and ceilings

6.3.4 Light façades: Curtain wall systems

The acoustic performance of curtain wall systems which usually make up the steel building envelope is obtained through construction similar to that of internal partitions:

- External cladding
- Internal facing
- Air cavity with a filling of an absorbent mattress (mineral wool).

The careful application of all these façade components is a pre-requisite to ensuring a satisfactory efficiency.

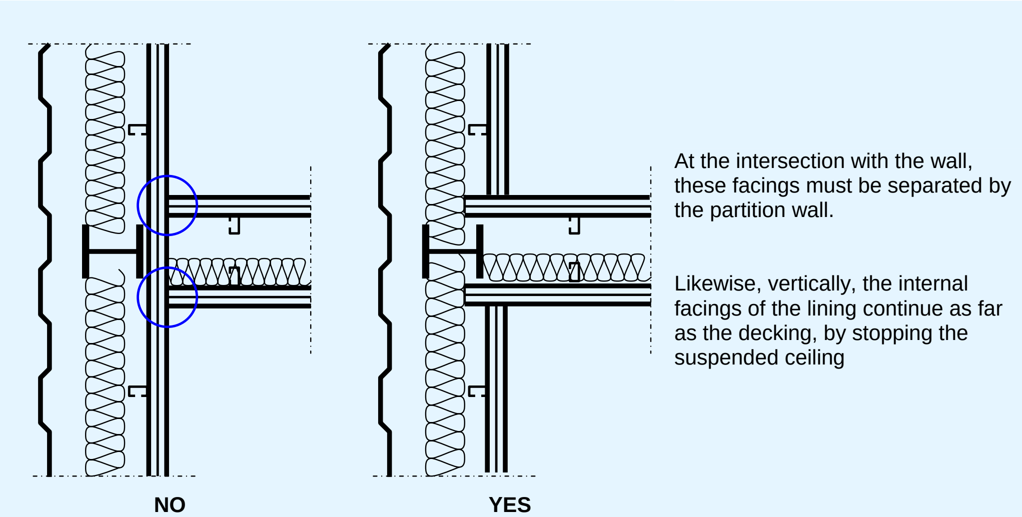


Figure 6.9 Horizontal cross section at the junction between façade and partition

6.3.5 Steel roofing systems

There are special techniques for treatment of metal roofing (film or spraying) in order to reduce the noise of impact caused by rain.

6.4 Thermal performance

In order to guarantee an acceptable level of thermal comfort for the occupants of buildings with controlled energy consumption, national regulations determine the material requirements for thermal performance. These depend on the building end-use and location.

The requirements can be defined in terms of:

- Restrictions on energy consumption needed for thermal comfort
- Restrictions on indoor temperature during the summer
- Minimum thermal characteristics of envelope and equipment (restricting heat loss – effect of thermal bridging).

Section 6.3 dealt with different ways of conforming with regulatory requirements for the acoustic performance of steel buildings. The provisions do for the various partitions typically use mineral wool as a mattress in the composite walls and its presence in the walls that surround the rooms also protects them from heat loss.

Between two floors, for example, calorific loss is reduced because layers of mineral wool are used in the composition of the floors (above and below).

Separating the two layers of insulation means that the type and thickness of the materials can be varied, thereby eliminating a large amount of thermal bridging.

Insulation materials include rock wool or glass, polyurethane foam and polystyrene foam.

The risk of direct temperature transfer between the metal parts in contact with the outside and the inside areas of the wall must be dealt with at the level of the fittings and joints.

6.5 Durability of steel structures

This Section covers the durability of steel building components. Sustainability of the material itself, particularly in respect of recycling, is discussed in Section 7 of this document.

Damage to a steel construction component arises mainly from two phenomena: fatigue and corrosion. Routine multi-storey buildings covered in this document are not affected by fatigue. This Section is therefore concerned only with the corrosion.

It is important to note at the outset that the steel frame buildings do not generally suffer major damage as a result of atmospheric corrosion. Moreover corrosion is not an issue for internal steelwork.

Even if, in the absence of adequate protection, structural elements subjected to normal atmospheric conditions may rust on the surface, this phenomenon is rarely the cause of damage to buildings, as long as a few elementary precautions are taken.

In contrast, the atmospheric conditions in some regions, such as coastal areas with a saline climate, or where there are industries that give rise to corrosive vapours, may result in steel structures having to be protected and maintained.

6.5.1 The phenomenon of corrosion

Corrosion is caused by the formation of metal salts on the surface of the steel component when a metal is combined with other elements. For example, iron corrosion leads to the production of iron oxide.

The corrosion process may be:

- Chemical: through reaction between the metal and a gas phase or liquid.
- Electrochemical: formation by electric current and oxidation of the anode.
- Biochemical: by attacking bacteria.

Steel corrosion

Rust is the result of steel corrosion and is mainly composed of iron oxides and hydroxides, which grow in the presence of moisture and oxygen content in the atmosphere.

The oxide layers are generally non-adherent and oxidation spreads steadily. The parts lose weight linearly as a function of time.

The corrosion product does not protect the steel.

Atmosphere and climate are parameters that have a significant influence on the aggressiveness of corrosion.

Atmosphere

The general atmospheric conditions at the building location affect the rate of corrosion: there are four general conditions:

- Rural: alternation of wet and dry atmosphere – absence of pollutants
- Urban: alternation of wet and dry conditions – present of sulphur dioxide (SO_2)
- Marine: high relative humidity – presence of chlorides which accelerate corrosion.

Industrial: presence of chemical agents – aggressive corrosion linked to degree and rate of pollutants

Climate

Heat and humidity are factors which accelerate the phenomenon of corrosion. In tropical climates, aggressive corrosion in rural environments is comparable with that in large industrial areas in temperate climates.

Some elementary precautions

In steel construction design, every means of limiting the effects of corrosion should be adopted:

- Avoid creating areas of moisture and water retention for elements which are exposed to weather
- Avoid contact between materials which have different electro-chemical potentials (e.g. aluminium and unprotected steel).

Protection of steel construction elements

It is advisable to adapt the degree of protection to the conditions in which the steel construction elements are installed.

There are two main forms of protection:

- Painting
- Galvanizing.

6.5.2 Paint protection

Table 6.6 summarizes common coating systems for corrosion protection.

It is worth noting that steel structures located inside a building where the atmospheric conditions are neither wet nor aggressive, and are permanently protected from the weather, would not suffer corrosion to the extent that it affects their resistance, even if they were not protected. However, what cannot be excluded is the unattractive appearance of rust: this can be prevented by applying a light paint coating.

Surfaces which remain unprotected must be visible in order to detect any unexpected degree of corrosion.

Table 6.6 Protection and thickness of coating

Conditions of use	Traditional anti-rust coating	Coated steel products
Elements incorporated in floors and façades, protected in absence of humidity	1 or 2 primer layers of anti-rust paint, 40 to 50 microns thick	Lacquered and painted products: 15-20 microns thick
Elements inside buildings without constant humidity	1 primer of anti-rust paint, 1 paint finish, 60 to80 microns thick	Lacquered and painted products. 1 paint finish. 60 microns thick
Elements inside unheated buildings or where humidity is high	2 primers of anti-rust paint. 1 intermediate layer of paint, 1 finish of paint, 80 to120 microns thick	Lacquered and painted products: 1 to 2 finishes of paint 80 to100 microns thick or Galvanized or pre-lacquered products
Elements in contact with aggressive external atmosphere, humid climate, urban or industrial regions	2 primer layers of anti-rust paint, 1 intermediary layer of anti-rust paint, 1 finish of anti-rust paint, 120 to 200 microns thick	Lacquered and painted products + 2 finishes of paint 100-120 microns thick Or: Galvanized or pre-lacquered products
Elements in contact with marine environment	2 primers of anti-rust paint or galvanizing/metalizing with 1 layer of zinc 1 intermediary layer of anti-rust paint, 1 paint finish, more than 150 microns thick	Lacquered or painted products + 2 layers of paint with high content of zinc or Galvanizing or metalizing + paint with high content of zinc Or: Pre-lacquered products

The steel elements are usually delivered to site with a surface coating consisting of an anti-rust primer. Once the elements are installed, it is necessary to touch up any coating which has deteriorated during assembly.

Although elements embedded in concrete are generally not painted, those parts which are not fully covered by concrete are often prone to corrosion and must be carefully protected (including column ends).

For those parts of the elements concerned, the welds are performed and checked before applying surface protection. The welding procedure must be adapted for pre-painted products.

Estimated life of paint protection: 8 to 10 years to first maintenance

6.5.3 Protection by galvanizing

The principle of galvanizing is the formation of protective layer of zinc and zinc-steel alloy on the surface of the steel parts in order to protect against corrosion.

The galvanized layer which is gradually oxidized to form corrosion products that are generally adhesive.

However, this form of protection is time limited and loses its effectiveness when all of the zinc coating has corroded.

Speed of corrosion and life of protection

Atmospheric conditions and climate have a direct impact on the rate of corrosion. Polluted industrial conditions near the sea are obviously more aggressive than the rural hinterland.

Depending on atmospheric conditions, the corrosion rate varies between 0,1 microns/year and 8 microns/year.

EN ISO 14713[1] provides guidance on the average annual zinc corrosion rate. This allows lifetimes to be estimated according to the coating thickness.

Estimated life of protection by galvanizing: approximately 25 years

Aesthetic appearance and painting

All galvanized steel can be painted to alter the surface appearance. Painting greatly enhances the life of the galvanized steel. Maintenance painting of galvanized steel is very easy: a brush is used to apply new layer of paint to the damaged area. The paint can also be applied as an additional form of corrosion protection in environments where acidic solutions may attack the surface coating.

Galvanizing processes

Zinc can be applied either by immersion or spraying (metalizing solution) or by electrolysis. Immersion is generally used for new parts, for dimensions compatible with the size of the baths. Spraying is used instead for renovation work or for larger building elements. Electrolysis is suitable for small parts and batch processing (e.g. bolts).

Some observations

Welding: Before welding galvanized parts, it is recommended that the coating is removed in the area of the weld seam. After sealing, the affected area will be protected by a zinc-rich paint.

Exposure to fire: A galvanized steel part that is exposed to fire behaves like uncoated steel and there is no improvement in fire resistance.

6.6 Service integration

6.6.1 General remarks

A multi-story building, regardless of end use, is the combination of multiple elements or sub-elements that contribute to its performance: not only the structure and envelope, but also the technical installations and services which sustain the life of the building.

The control of interactions between the services and the building structure should allow:

- Ease of access to services for maintenance purposes
- Facility to replace elements where their life span is shorter than the structure
- Prevention of nuisances arising from vibration of structures due to operation of equipment.

The main services to be installed are:

- Heating and air conditioning,
- Ventilation,
- High and low current power supplies.

Services to the whole building are supplied using horizontal and vertical systems.

6.6.2 Horizontal systems

The steel structure and envelope offer very efficient methods of service integration using horizontal systems, as illustrated in Table 6.7. It is worth highlighting the use of cellular beams in this context (see sections 3 and 4 in this document for a description of these products). Since services can pass directly through these beams, the floor-to-floor height can be reduced. In some cases, this allows another floor to be added without altering the overall height of the building.

The standard configuration of cellular beams (regularly spaced cells of the same size) can generally be adapted to create larger openings, especially near the mid-span, in order to allow the passage of large rectangular ducts (Figure 6.10).

6.6.3 Vertical systems

Steel construction and standard envelope systems also offer flexible integration of vertical systems, due to open spaces in the wall thickness.

Achieving floor openings, and changing their location during the life of the building, is facilitated by the use of composite dry floors.

It is best to prevent the passage of services through hollow sections (between flange plates) because of potential problems with beam/column connections and in event of application of fire protection coating.

The integration of vertical pipes in tubular columns is not recommended because of lack of access for maintenance.

Table 6.7 Integration methods for horizontal systems

Sytem	Feature
Visible systems	For economical, technical or architectural reasons, services can remain visible. The advantage lies in access to services, while the disadvantage is the risk of shock on unprotected pipes.
Above ceiling systems	Services can be installed above floors then concealed by false open or closed ceilings and can be fully or partially dismantled. The ceiling void is cut alongside the acoustic partitions, or for reasons of fire safety. Services can pass through the cellular beams or truss.
Systems with decking surface	This arrangement is only possible for certain types of small diameter pipe systems.
Plinth or breast systems	Installation of composite façade walls facilitates this arrangement, with ease of service offsets and connections through elimination of constraints imposed by heavy walls.
Systems on floors	Raised floors always consist of steel structures. The space created between the floor and the false ceiling allows movement of services with large number of ducts. These offer full accessibility and adaptability.

Figure 6.10 Cellular beams and service integration

7 STEEL CONSTRUCTION AND SUSTAINABILITY

The preoccupations of the sustainable development are of particular concern for the construction sector, which is responsible for 25% of greenhouse gas emissions and for 40% of the primary energy consumption. They constitute a major stake for all the involved professionals.

It is a question today of designing and of realizing creative projects which integrate values and new techniques. Steel is the mainspring in our quest to improve the quality of our buildings and their impact on our living environment.

General principles are established according to three main considerations: ecological, economical and socio-cultural, although the methods for determining their impact have not yet been agreed on an international scale.

The sustainability of buildings concerns a range of issues related to choice of materials, construction process, occupation and end of life. These issues may be expressed in terms of specific criteria, such as energy materials use, waste minimization, reduction of primary energy use (and CO_2 emissions), pollution and other global impacts.

Figure 7.1 Praetorium building in La Défense (Paris) with 'High Environmental Quality' label

7.1 Life cycle

Steel is an excellent solution for conserving raw materials, thanks to its recyclability. It can be infinitely recycled without losing its properties.

Today, the production of steel in Europe consists of 50% recycled metal, reducing the need for ore; for certain products intended for construction, this rate can reach up to 98%. This re-use of the material is in particular made possible by its magnetic properties facilitating the sorting.

For 25 years, the control of energy and the reduction of CO_2 emissions during production have led to vast improvements in developing new steel materials and taking into account life cycle of materials and products. The European steel industry has substantially contributed to the energy efficiency and the reduction in CO_2 emissions.

Between 1970 and 2005, the European steel industry reduced CO_2 emissions by 60%; between 1990 and 2005, this reduction was 21% (source Eurofer). In the same period, crude steel production increased by 11.5% (source Worldsteel for EU15).

Other solutions are already underway to improve these results.

Steel is a neutral material which emits no polluting substance or element that is harmful to the environment or health, even under the influence of corrosion.

Galvanizing and painting (carried out in the factory) are corrosion protection systems that guarantee the durability of steel up to 25 years.

Maintenance of steel is limited to regular follow-up and periodic painting.

7.2 Advantages of steel products for construction

An Environmental Product Declaration (EPD) is now a widely developed approach for construction products. Based on ISO 21930[2] the overall goal of an EPD is to provide relevant, verified and comparable information to meet various customer and market needs.

Using life cycle assessments, the steel industry has already provided several EPD for generic products as well as branded systems. The energy and lighting consumption during service life exceeds the embodied energy in the structure.

Thanks to the efficient use of materials, steel construction minimizes waste in manufacture and on-site, because all steel off-cuts and drills are sent for re-cycling into new steel components. Typically, the average steel wastage and re-use is about 2%, in comparison with the European average of 10% for all the products used on-site.

The excellent weight-resistance ratio of the material offers incomparable constructive and architectural possibilities. This performance opens the way to the reducing the weight in buildings, using thin walled structures in the façade. These features offer a large amount of space with light and vast possibilities for architectural integration.

The association of steel with other materials offers many efficient solutions for thermal and acoustic insulation.

For the envelope, the metallic construction is generally designed with an external thermal insulation; walls are built from industrialized systems, metallic or not (glass, wood, concrete, terra-cotta, plaster, etc.), which offer high levels of thermal performance. The heating and ventilation systems can then be chosen for optimal energy behaviour.

The range of qualities opens the architectural choices and allows the optimized selection of the processes, the materials and the methods of construction, especially by considering the global life of the building to be realized up to its demolition.

7.3 Steel-intensive solutions for buildings

For buildings there are several environmental initiatives across Europe. These approaches can be quantitative or qualitative, using variable criteria. However, some subjects are common, but with different treatments, for which steel solutions bring firm answers.

The harmonious integration of the building with its surrounding environment

The choice of a steel frame for a building project allows the designer a large freedom of shape and the flexibility to adapt work to the constraints of the site.

Used for façades or roofing, steel products offer the architect a range of textures, geometries and colours to respond to the most sensitive and the varied of contemporary sites, whether a historical city centre or in the countryside.

Lightness of the structures and the flexibility of spaces

A frame made with columns and beams is typical in steel buildings. Without load-bearing walls, the construction is lighter; the impacts on the foundations and the ground are lesser.

It is also easier to remodel internal spaces according to the changes of use.

A structure with connected components is an efficient solution for vertical extensions as well as in the renovation of an existing building.

Less on-site problems

Steel products and associated elements are industrially made, of high precision. They are delivered with accurate dimensions for on-site assembly. Due to the higher level of pre-fabrication, implicit in steel-intensive constructions systems, speed of construction is increased.

The construction site is transformed, with reduced deliveries, precise and appropriate assembly, less storage and no waste.

Maintenance

Steel solutions provide durability and facilitate cleaning and replacement of components.

Services (fluids, ducts, etc) are generally placed in the ceiling void. The maintenance and the possible reconfiguration of the services are then facilitated, especially in the presence of cellular beams. This flexibility allows the different levels to be completely refitted.

At the end of life, the demolition consists of a clean dismantling, for a complete recovery of materials.

Re-use of steel profiles

In Western Europe, a study has shown that about 11% of profiles in the construction sector are directly reused after demolition, without remoulding (ECSC Report ‘LCA for steel construction’. Document RT913. July 2002. Steel Construction Institute).

Creating a safe and comfortable internal space

All combinations of wall components can be accommodated.

Steel solutions in combination with additional products contribute to the excellent sound insulation through the ‘mass-spring-mass’ principle.

For thermal comfort, steel allows the design of ‘evolved’ façades, adapted to the various climatic conditions:

- Double-skin façades, implementation of a layer of ventilated air,
- Fixed or mobile solar control mechanisms

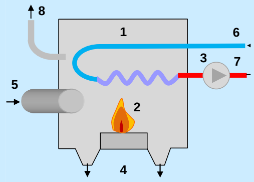
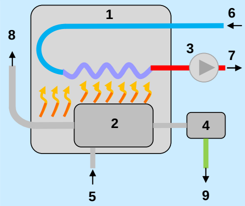
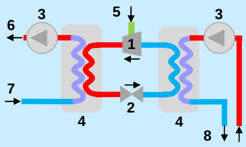
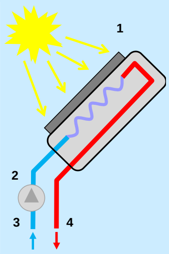
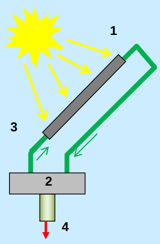
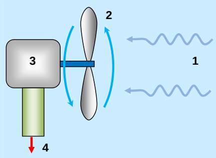
Integration of alternative technologies on steel buildings

Alternative Energy Technologies (AET) are integrated into building design for a wide range of reasons but typically the primary motivators are green aspirations and planning restraints such as ‘Grenelle’, which will require a certain percentage of a building’s energy consumption to be provided by additional benefits from using AET, including renewable energy.

AET provide environmental benefits over the use of standard energy supply. Moreover, they have a very low impact on steel buildings. The main concerns for AETs implantation are:

- Plant Room: The location of the plant room and spatial restrictions can impact on the viability of specific technologies
- Shading: the shape of the new building may restrict the location of solar PV panels.
- Roof Orientation: The orientation and the shape of the roof can be a limitation on energy output, for either solar hot water collectors or photovoltaic panels.
- Reliability: If an unproven technology is used then it may not be reliable and so the desired carbon savings cannot be made.

Table 7.1 Renewable energy sources

Type		Comment
Biomass heating 1 Boiler 2 Burner 3 Pump 4 Ash removal 5 Biomass fuel delivery 6 Cold water 7 Hot water 8 Flue gas		The system requires a basic plant room for the boiler and storage for the fuel. This can be fully integrated in the building, creating a steel storage with a steel frame.
Combined Heat and Power (CHP) 1 Boiler 2 Engine 3 Pump 4 Generator 5 Main gas supply 6 Cold water 7 Hot water 8 Flue gas 9 Electricity		The system only requires a typical plant room, entirely compatible with a steel frame construction for mixed-use developments and sites with high hot-water loads. It is generally suitable for swimming pools, hotels and hospitals,
Ground Source Heat Pumps (GSHPs) 1 Compressor 2 Expansion valve 3 Pump 4 Heat exchanger 5 Electricity in (AC 230V) 6 Hot water supply 7 Cold water return 8 Return to heat source 9 Supply from heat source		GSHP's can be applied anywhere given that there is enough space for plant room and ground loops or wells. Often, areas used for car parks or gardens can be used. All steel buildings are suitable for this technology.
Solar Hot Water Collectors 1 Absorber plate 2 Pump 3 Cold water supply 4 Hot water return		Solar equipment can be installed on a flat roof without impact on the steel structure using a cantilever, a steel structure to support the panels (however, system weight, wind and damp-proof cloth resistance have to be considered). On a pitched roof, the system can be implemented by using subsidiary steel work, clips or directly integrated in the roofing such as PV tiles or on a façade, with simple rails to allow the fastening.
Solar Photovoltaics 1 Photovoltaic module 2 DC electricity generation 3 Inverter 4 Electricity		
Wind Turbines 1 Wind energy 2 Turbine blades 3 Generator 4 Electricity		A small scale wind turbine requires little infrastructure for its inclusion; only an allowance for cable ducts from hard standing areas to a suitable plant room. If directly mounted on steel frame buildings, it is essential to consider the additional loads, vibration and noise. Small wind turbines can be suitable for steel buildings, such as commercial buildings, aircraft hangars, or industrial buildings as they are best located in a clear wind stream, away from obstructions and surface roughness.

8 CONCLUSION

Thanks to its outstanding mechanical performance, to the freedom of technical prowess it affords, to its flexibility of use in different types of buildings, to its plastic and aesthetic potential and the creativity it inspires, steel has a natural place in the pantheon of materials for architectural design.

When an architect chooses steel, he knows this is a choice of no small consequence. First this choice implies rigorous design, awareness of the functionality of each of the elements that make up the design, and analysis of all stages in the building process – from drawing board to routine management of the completed project. Second, the choice is an expression of affirmation, of putting ones mark on a design, a way of conceiving and perceiving, a willingness to contribute to the urban landscape, to integrate with light and air into the urban fabric. Steel is a form of expression which gives meaning to architectural design.

Choosing steel to design a multi-storey building is to choose a material which offers low cost, strength, durability, design flexibility, adaptability and recyclability. It also means choosing reliable industrial products which come in a huge range of shapes and colours; it means rapid site installation and less energy consumption. It means choosing to commit to the principles of sustainability. Infinitely recyclable, steel is the material that reflects the imperatives of sustainable development. In conclusion, choosing steel means choosing a greater freedom of construction, of architecture. It means injecting style into the buildings and the cities of tomorrow.

REFERENCES

1 EN ISO 14713 Zinc coatings. Guidelines and recommendations for the protection against corrosion of iron and steel in structures.

2 ISO 21930:2007 Sustainability in building construction. Environmental declaration of building products