

# Concrete Framed Buildings



A guide to design and construction



## Contents

Benefits of concrete framed buildings .....	3
Structural forms.....	6
Flat slabs .....	8
Post-tensioned slabs .....	10
Ribbed and waffle slabs .....	12
Beams and slabs .....	13
Hybrid concrete construction .....	14
Precast concrete .....	16
Crosswall .....	18
Concretes for framed buildings.....	20
Cost and programme .....	23
Sustainability .....	24
Summary .....	27
References.....	27

## Introduction

**This publication sets out to help the designer come to an informed decision, giving likely structural options for a concrete frame, with useful points to note written by engineers for engineers. It was first published in 2006, and this revision brings it up to date with the latest techniques, including designs to Eurocode 2.**

At the start of each project, a decision is made about the form and material of the structural frame. These key decisions are frequently influenced by whatever frame the contractor, client, QS or engineer may have used on a previous building. This publication sets out to help design teams come to an informed decision, giving likely structural options for a concrete solution. The guide is intended for use by structural engineers, but clients and other members of the design team will also find it useful. The guide sits alongside The Concrete Centre publication, *Economic Concrete Frame Elements to Eurocode 2* (ECFE) [1].

Construction should not just be about achieving the cheapest building possible, but providing best value for the client. The best value may be about costs, but also includes speed of construction, robustness, durability, sustainability, lettable space, etc. Notes on how concrete meets these value criteria are included here, both in the general case and specifically for the frame options detailed.

Concrete frame construction has changed over the past 20 years and continues to develop. Common types of concrete frame construction are detailed in the following pages, together with the markets for which they are suitable. A section on recent developments in concrete gives an insight into what is available to the designer.

Sustainability is an issue in today's world. Concrete can help provide a sustainable solution to the changing climate, through the use of its high thermal mass. Concrete is also locally sourced, indeed the raw materials for concrete are ubiquitous, and at the end of its life, it is fully recyclable.

**Cover image:** Concrete frame construction at the former Battersea Power Station site, London. © Alamy

**This page:** Post-tensioned one way slab and band beam construction was used at Cardinal Place, London.

# Benefits of concrete framed buildings

**Concrete's unique flexibility provides a wide range of framing options and design/construction solutions to suit the project's exact needs. Later pages outline particular benefits and constraints.**

**In assessing suitability, designers and cost consultants should consider the following issues to achieve the best solution.**

## Whole Life Value

The frame is the key structural element of any building. Frame choice and design can have a surprisingly influential role in the performance of the final structure, and importantly, also influence people using the building. So, cost alone should not dictate frame choice. Many issues should be considered when choosing the optimum structural solution and frame material that give best value for the construction, operational, use and demolition stages. Inherent benefits – fabric energy storage, fire resistance and sound insulation – mean that concrete buildings tend to have lower operating costs and lower maintenance requirements. This is an important consideration, particularly for owner-occupiers and others who are responsible for the operation of the building.

## Cost and Programme

### Programme

Generally, in-situ concrete-framed buildings take no longer to construct than steel-framed buildings: indeed, they can be faster. Prerequisites for fast construction in any material are design discipline, repetition, integration, simplification and standardisation of design details. Rationalising reinforcement, designing and detailing for prefabrication, precasting or part-precasting can help progress concrete construction on site and many more operations into controlled factory conditions, improving site safety and quality. Many contractors appreciate the opportunity to discuss buildability and influence designs for construction. More important, however, is the whole project programme. Concrete provides a safe working environment and semi-internal conditions, allowing services installation and follow-on trades to commence early in the programme, while flexibility allows accommodation of design changes later in the process.

### Speed of construction

Concrete is highly compatible with fast programme construction, from rapid mobilisation at the start through modern methods of construction, including sophisticated formwork systems, post-tensioning, and precast elements. Modern formwork systems have markedly increased construction rates. It is now standard to achieve 500m<sup>2</sup> per week per crane. Cellular structures can be built at a rate of up to 50 bedrooms per week.

The speed of the various forms of concrete construction is given in the specific information in the Structural Forms section of this publication, see page 6.

### Frame costs

While material costs fluctuate significantly over time, the difference between steel and concrete frame costs remains insignificant, with full fit-out whole-building costs broadly similar. These whole project initial costs come from a cost comparison study [2]. Prices shown below are as of June 2013.

6 storey office	RC flat slab	£26,224,107
	Steel composite	£26,619,649
3 storey office	RC flat slab	£6,525,807
	Steel composite	£6,601,819

### Foundation costs

Foundations typically represent approximately 3% of the whole project initial cost. For the heaviest reinforced concrete solution, foundations will be more expensive, but still represent only a small percentage of the whole and can be offset by using post-tensioned slabs which are typically 15% lighter.

### Cladding costs

The thinner the overall structural and services zone, the less the cladding costs. Cladding can represent up to 25% of the construction cost, so it is worth minimising the cladding area. This can be readily achieved with a concrete flat slab, particularly if post-tensioned, and a separate services zone.

To obtain best value, consider early specialist contractor involvement. UK concrete frame contractors have expertise that can reduce costs and maximise value when harnessed early in the design process.



## Performance in Use

### Thermal mass

A concrete structure has a high thermal mass. Exposed soffits allow fabric energy storage (FES), regulating temperature swings. This can reduce initial plant costs and ongoing operational costs, while converting plant space to usable space. With the outlook of increasingly hot summers, it makes sense to choose a material that reduces the requirement for energy intensive, high maintenance air-conditioning.

### Fire protection

Inherent fire resistance means concrete structures generally do not require additional fire protection. This removes time, costs, use of a separate trade and ongoing maintenance to applied fire protection.

### Acoustics

Additional finishings to walls and floors are often required to meet Part E of the Building Regulations. The inherent mass of concrete means additional finishings are minimised or even eliminated. Independent testing of 250mm thick concrete floors in a new tunnel-form block of student accommodation gave results exceeding requirements by more than 5dB for both airborne and impact sound insulation. Separating walls comprising 180mm concrete with a 2mm plaster skim finish also met the pre-completion testing requirement [3].

### Vibration control

For concrete buildings, vibration criteria for most uses are covered without any change to the normal design. For some uses, such as laboratories or hospitals, additional measures may be needed, but these are significantly less than for other materials. In an independent study [4] into the vibration performance of hospital floors, concrete emerged as the solution least in need of significant modification to meet the stringent criteria. This gives great flexibility for change in use and avoids the cost penalties of providing extra mass and stiffness.

## Coordination

### Design flexibility

Concrete can be used in a variety of ways to suit the designer, the client, the building and the site – using cast in-situ concrete, or precast concrete from the factory. A 'Hybrid' combination of the two is increasingly popular, combining the benefits of each form for best value. It is important to consider possible forms of construction in the earliest design stages, allowing change to be easily effected, and value unlocked.

### Services coordination and installation

Mechanical and electrical services are an expensive and programme-critical element in construction, with significant maintenance and replacement issues. The soffit of a concrete flat slab provides a zone for services distribution free of any downstand beams. This reduces design team coordination effort and risk of errors. It allows flexibility in design and adaptability in use. A flat soffit permits maximum off site fabrication of services, higher quality work and quicker installation. Horizontal services distribution below a profiled soffit can add up to 15% to the cost of the M&E package in comparison to a flat soffit.

Openings in the slab for service risers can be accommodated simply during design, and formed during casting, or cut later to suit. For the longest spans, wide shallow beam solutions provide large areas uninterrupted by secondary beams, and the freedom to route ducts under the shallow main beams.

### Partitions

Sealing and fire stopping at partition heads is simplest with flat soffits. Significant savings of up to 10% of the partitions package can be made compared to the equivalent dry lining package abutting a profiled soffit with downstands. This can represent up to 4% of the frame cost, and a significant reduction in programme length.

Construction of a multi-purpose nine-storey superstructure at Rathbone Square, London. Courtesy of Careys.



## Whole life

Concrete is durable, frequently allowing building reuse, rather than replacement. Demolished concrete is 100% recyclable, as are reinforcing bars - indeed all UK rolled reinforcement is fabricated from recycled steel. The constituent parts of concrete (water, cement and aggregate) are all readily and locally available to any construction site, keeping any impact of transporting raw materials low. This is examined in more detail in the Sustainability section, see page 24.

### Robustness and vandal resistance

Concrete is, by its nature, very robust, capable of withstanding explosions, accidental damage and vandalism.

### Minimal maintenance

Unlike other materials, concrete does not need any environmentally unfriendly coatings or paint to protect it against deterioration. Properly designed concrete is maintenance free.

### Adaptability

Markets and working practices are constantly changing, therefore it makes sense to consider a material that can accommodate changing needs or be adapted with minimum effort. A concrete frame can easily be adapted to other uses. Holes can be cut through slabs and walls relatively simply, while there are methods to strengthen the frame if required.

### Air tightness

Part L of the Building Regulations requires pre-completion pressure testing. Failing these tests means a time consuming process of inspecting joints and interfaces, resealing where necessary. Concrete edge details are simpler to seal, with less failure risk. Some developments have switched to concrete frames on this criterion alone.



A 13-storey concrete frame under construction at Queen Elizabeth University Hospital, Glasgow. Courtesy of Dunne Group.

## And more benefits

### Speed

Concrete construction has undergone a revolution in speed and efficiency in recent years. Forming the concrete into shape is potentially the most costly and labour intensive part of the process. However, modern high efficiency modular formwork standardises and mechanises this process. It usually employs standardised formwork systems which are simple and quick to erect and move. Alternatively, elements may be factory precast, requiring only assembly, or stitching together with in-situ elements. The result is an economic and swift process, capable of excellent quality and finishes to suit the frame's needs.

### Aesthetics

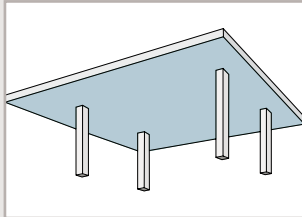
Internal fair-faced concrete can be both aesthetically pleasing and durable, ensuring buildings keep looking good with little maintenance. Precast concrete cladding also looks good. It is available in many different colours, textures and finishes, including brick, stone and tile faced.

Nash Mills development, Hemel Hempstead. A six-floor reinforced concrete frame residential building. Courtesy of Coinford Construction.

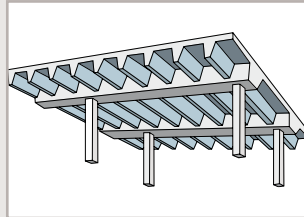


# Structural forms

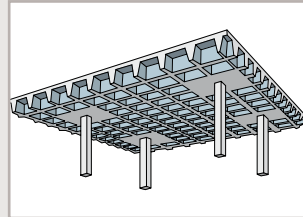
Concrete frame construction comes in many forms; here are the typical ones which are detailed in this publication.



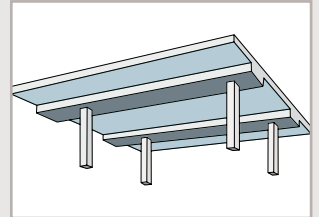
Flat slab – page 8  
Post-tensioned slabs – page 10



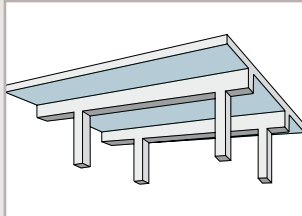
Ribbed slab – page 12



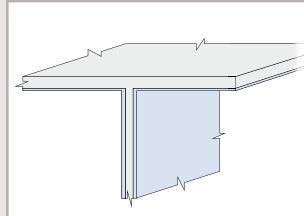
Waffle slab – page 12



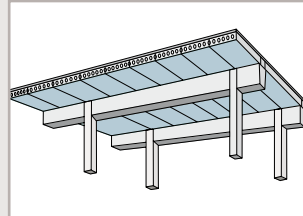
Band beam and slab – page 13



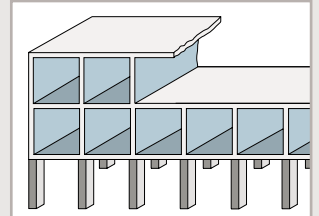
Deep beam and slab – page 13



Hybrid concrete construction – page 14

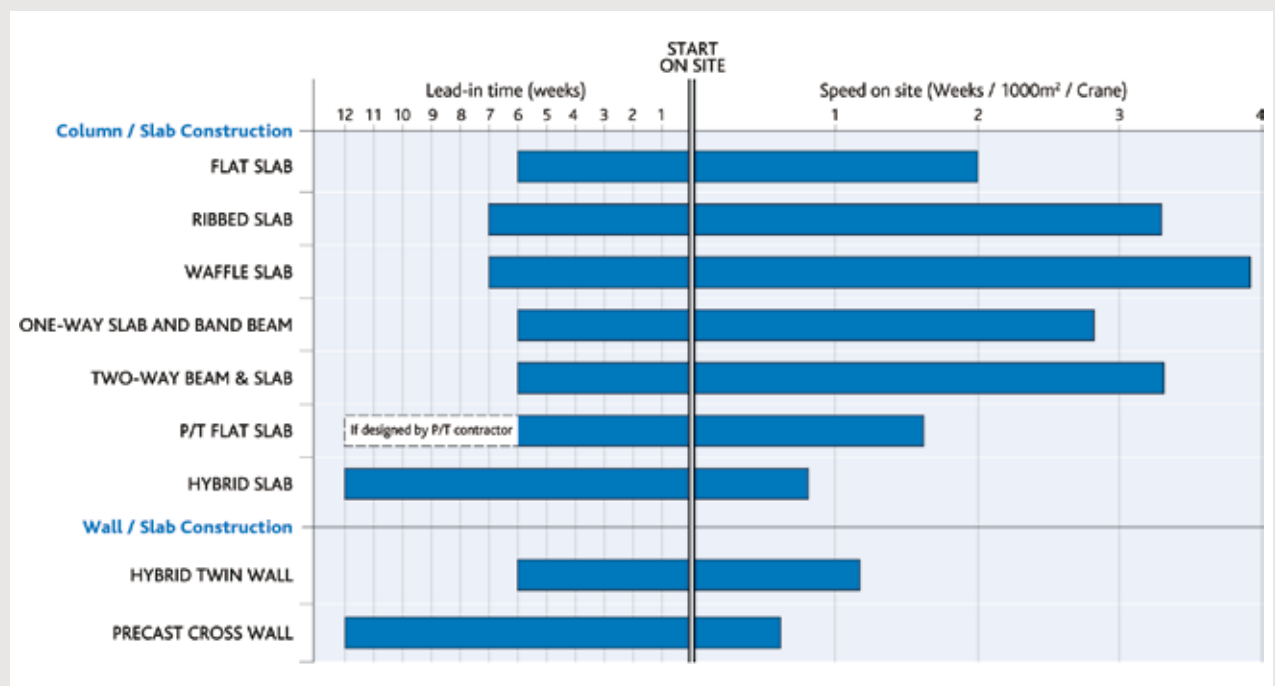


Precast concrete – page 16



Crosswall – page 18

## Lead-in times and speed of construction

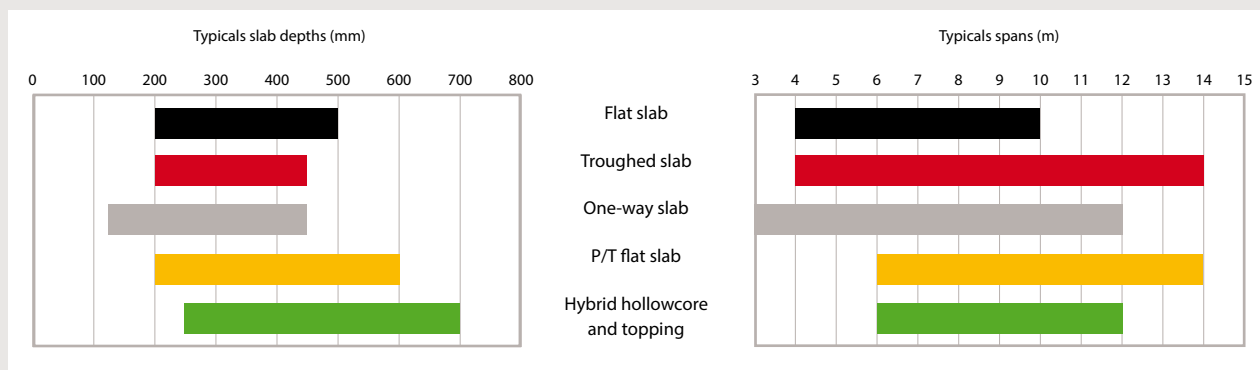


The diagram shows approximate lead-in times and construction speeds for each of type of construction detailed in this publication. Times and speeds are typical but will vary, depending on availability of contractors and materials and site constraints.

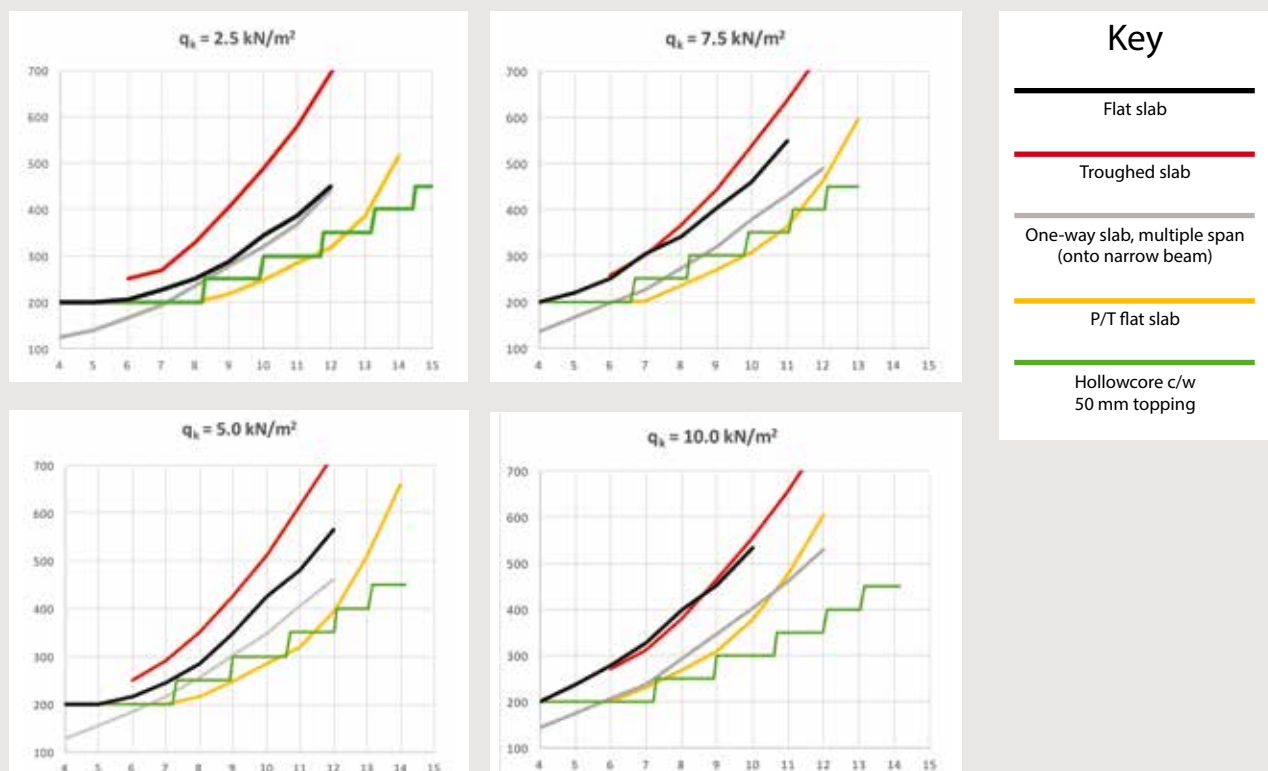
## Span and depth of construction data

These graphs show typical depths required for different spans for each slab form. The design has been undertaken using Eurocode 2 (BS EN 1992-1-1 and UK NA) using a superimposed dead load of  $1.5 \text{ kN/m}^2$ , and C30/37 strength class concrete. The graphs assume that multiple, square bays are considered, except for the hybrid hollowcore and topping which is assumed to be a single span.

The diagram below shows the economic spans and the typical range of depths for different types of floor construction. It covers imposed loads of between  $2.5$  and  $10 \text{ kN/m}^2$ .



The line graphs show span and depth information for different live loads for each slab form. For loads not shown, interpolation between graphs is acceptable. For further information on this, the reader should use Concept.xls [5], a spreadsheet allowing 13 different reinforced concrete slab forms to be considered.





# Flat slabs

**Flat slabs are highly versatile elements widely used in construction, providing minimum depth, fast construction and allowing flexible column grids.**

## Points to Note

### Design

Flat slabs may be designed using the equivalent frame method set out in EC2-1-1 Annex I, finite element analysis (FEA) programmes or yield line analysis [6]. Use FEA [7] or yield line analysis for irregular grids.

Punching shear around the column heads can be the limiting factor on either depth of slab or column size. Shear reinforcement can be provided by links, shear rails, beam strips (to the American code) or steel cruciforms.

Deflection can be a limiting factor on depth. In tests, corner bay deflections have been shown to be greater than in other bays, as the membrane action in the slab plate is less at the corners. It is therefore sensible to consider

the corner bay for reinforcement design, shortening the end grid to make reinforcement similar across all spans.

There is a limit to the moment that can be transferred into the edge columns. If the moment from the design method used is greater than allowable the moment should either be redistributed to allow the moment to be within the limit, or column width or slab depth should be modified. In residential structures, blade columns at right angles to the slab edge are popular but they demand early verification of punching shear and fire design.

### Construction

Construction of flat slabs is one of the quickest methods available. Downstand beams should be avoided wherever possible as forming beams significantly slows construction. Edge beams need not be used for most cladding loads [1].

Reinforcement should be rationalised fairly heavily as this gives the most economic solution. Detailing can be done by the designer or the contractor. Prefabricated reinforcement mats, normally detailed by the supplier, can speed up construction on site.

The School of Architecture and Construction at the University of Greenwich has in-situ flat slabs of varying depths – some up to 450mm thick. © VIEW





### Lead times

Lead times are very short as this is one of the most common forms of construction. If contractor reinforcement detailing or prefabricated reinforcement is used, lengthen lead time to allow for production and checking of detailing information.

### Procurement

This is one of the most common forms of concrete construction. All CONSTRUCT [8] members and many other concrete frame contractors can undertake this type of construction.

### Cost/whole life cost/value

Flat slabs are particularly appropriate for areas where tops of partitions need to be sealed to the slab soffit for acoustic or fire reasons. It is often the reason for flat slab to be considered faster and more economic than other forms of construction, as partition heads do not need to be cut around downstand beams or ribs.

Flat slabs can be designed with a good surface finish to the soffit, allowing exposed soffits to be used. This allows exploitation of the building's thermal mass in the design of HVAC requirements, increasing energy efficiency.

### Speed on site

With modern formwork systems, the average speed on site of flat slabs is approximately 500m<sup>2</sup>/crane/week.

### Mechanical and electrical services

Flat slabs provide the most flexible arrangements for services distribution as services do not have to divert around structural elements.

Holes through the slab close to the column head affect the design shear perimeter of the column head. Holes next to the column should be small and limited to two. These should be on opposite sides rather than on adjacent sides of the column. It is worth setting out rules for the size and location of these holes early in the design stage to allow coordination.

Large service holes should be located away from the column strips and column heads in the centre of the bays. Again, location and size of any holes should be agreed early in the design.

### Health and safety

Modern formwork systems can incorporate all edge protection and provide a robust working platform.

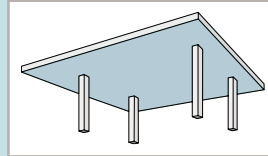
## ✓ CHECKLIST

### Flat Slab

#### Markets:

- ✓ Residential
- ✓ Commercial
- ✓ Hospitals
- ✓ Laboratories
- ✓ Hotels

#### Flat slab



#### Benefits:

- ✓ Cost
- ✓ Speed
- ✓ Flexibility
- ✓ Sound control
- ✓ Fire resistance
- ✓ Robustness
- ✓ Thermal mass
- ✓ Durable finishes

Modern formwork system at Eleven Brindleyplace, Birmingham.  
Courtesy of PERI Ltd.

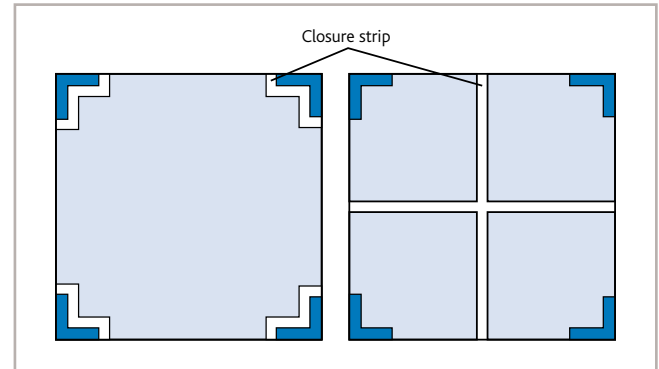


# Post-tensioned slabs

**Post-tensioned (PT) slabs are typically flat slabs, band beam and slabs or ribbed slabs. PT slabs offer the thinnest slab type, as concrete is worked to its strengths, mostly being kept in compression. Longer spans can be achieved as the compression effectively stiffens the prestressed slabs and beams.**

Post-tensioning can use bonded or unbonded systems. Currently the most common type is bonded. Bonded systems have tendons that run typically in flat ducts, grouted up after the tendons have been taken to full prestress. Bonded systems do not rely on the anchorages after the ducts have been grouted, with the prestress locked into the slab even if a tendon is inadvertently cut. Unbonded systems have tendons that run in a small greased protective sheath. Unbonded systems are more flexible, with no need for a separate grouting stage but require anchorages at each end.

Normal reinforcement is required wherever prestress is not present. This includes the edges of the slab and in any closure or infill strips. It is also needed at anchorages, where there are large bursting stresses due to high local forces. Normal reinforcement is also needed in unbonded systems for the ultimate load case. In bonded systems, this ultimate load case can be resisted partially or fully by the bonded strands.



Closure strips are required if the building has more than one core or stiff point.

Around column heads shear and bending reinforcement is required for both bonded and unbonded slabs.

There are a number of computer programs available for the design of post-tensioned slabs. They cover the design of the tendons, and any normal reinforcement.

A bonded post-tensioned slab just prior to the concrete being placed. Note the minimal amount of reinforcement required. Photo courtesy of CCL.



## Points to Note

### Design

For post-tensioned flat slabs, design tends to be based on limiting punching shear or deflection.

Post-tensioning should not be between two stiff points, e.g. cores, as the tension cannot be mobilised in the slab without pulling the stiff points together (or cracking the slab). Cores should, if possible, be placed in the centre of the building. If this is not possible, closure strips or proprietary dowels should be used, and concreted or fixed after the post-tensioning has been carried out.

Design should be carried out to Eurocode 2 and guidance is available in The Concrete Society Report TR43 [9].

### Construction

Contractors should be aware of the need to protect ducts and tendons from damage prior to concreting.

The tensioning jack needs to have a working space of approximately one metre. If the site is constricted it may be necessary to have a normally reinforced strip around the edge of the slab and prestress via a stressing pan.

### Procurement

Procurement of post-tensioned frames is done via a concrete frame contractor, who may well employ a specialist sub-contractor. All major frame contractors can provide post-tensioned frames. The contractor or specialist sub-contractor carrying out the works should be CARES-approved as this provides assurance that the contractor's health and safety procedures are approved and audited.

Procurement can be with a full design prepared by the designer or with a performance specification, suitable for a consultant to the frame contractor to be able to use to carry out the design. The performance specification should include:

- Floor and beam sizes (if critical)
- Design loads
- Hole locations
- Restraint locations

The designer and specialist post-tensioning designer should agree a design responsibility matrix, to ensure that all parts of the design are covered.

### Lead times

Lead times depend on the method of procurement. If the design is by the main designer, procurement is only slightly longer than for normal reinforced concrete. If the design of the post-tensioned slabs is by a specialist, lead in time should reflect work to be done before start on site.

### Cost/whole life cost/value

Post-tensioned slabs can be cheaper than the equivalent RC frame, particularly for spans exceeding 7.5m/8m.

### Speed on site

Post-tensioned slabs tend to be faster on site than reinforced concrete slabs due to the reduction in steel fixing required and the reduction in the volume of concrete. Formwork can also be struck earlier.

## ✓ CHECKLIST

### Post-tensioned slabs

#### Markets:

- ✓ Commercial
- ✓ Hospitals
- ✓ Car parks
- ✓ Residential
- ✓ Long spans

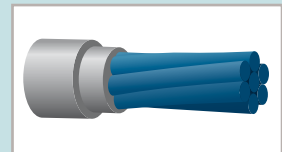
#### Benefits:

- ✓ Cost
- ✓ Speed
- ✓ Reduced material use
- ✓ Sound control
- ✓ Robustness
- ✓ Thermal mass
- ✓ Minimal deliveries
- ✓ Fire resistance
- ✓ Long span

#### Bonded



#### Unbonded



### Mechanical and electrical services

Holes for the vertical distribution of services can be provided without a problem between the tendons. If the required hole is too large to fit between them, the tendons can either be displaced around the holes or anchored at the edge of the hole.

### Health and safety

Post tensioned slabs are not an 'unexploded bomb'. If cut inadvertently the tendons do not whip out of the protective sheath or duct. In particular, the bonded systems, when grouted, are as safe as normal reinforcement.

Alterations can be achieved in bonded systems by back propping the span affected and cutting the ducts as necessary. Often no strengthening will be required, unless the new void is at a critical section.

Alterations can be achieved in unbonded systems by backpropping all the spans affected by the tendon(s) to be cut. The cut tendons can then be restressed against newly formed anchorages.

For a bonded system post-tensioned slabs can be demolished by normal methods. For an unbonded system, the slab should be backpropped, the anchors broken open and the tendons destressed before the slab is demolished.

Further information on post-tensioned slabs can be found in The Concrete Centre publication, *Post-tensioned Concrete Floors*.

# Ribbed and waffle slabs

**Ribbed and waffle slabs provide a lighter and stiffer slab than an equivalent flat slab, reducing the extent of foundations. They provide a very good form where slab vibration is an issue, such as laboratories and hospitals.**

Ribbed slabs are made up of wide band beams running between columns with typically equal depth narrow ribs spanning the orthogonal direction. A thin topping slab completes the system. Overall, they tend to be deeper than flat slabs.

Waffle slabs tend to be deeper than the equivalent ribbed slab. Waffle slabs have a thin topping slab and narrow ribs spanning in both directions between column heads or band beams. The column heads or band beams are the same depth as the ribs.

## Points to Note

### Design

Frequently ribs are designed as L-sections to allow a hole on one side of the rib. This allows design to proceed before the service holes have been finalised.

Waffle slabs work best with a square grid. Ribbed slabs should be orientated so that the ribs span the longer distance, and the band beams the shorter distance. The most economic layout is  $l_x:l_y = 4:3$ .

### Construction

Both waffle and ribbed slabs are constructed using table forms with moulds positioned on the table forms or with coffered precast planks. Speed of construction depends on repetition, so that the moulds on the table forms do not need to be repositioned.

### Lead times

Both ribbed and waffle slabs need moulds to be procured before starting on site. The lead-in times for these moulds depends on whether the mould is standard or needs to be fabricated.

### Procurement

All concrete frame contractors should be able to provide this type of construction.

**Exposed waffle slabs are excellent for providing the full benefits of thermal mass.**



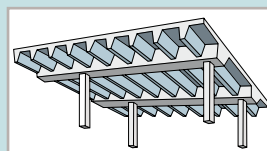
## ✓ CHECKLIST

### Ribbed and waffle slabs

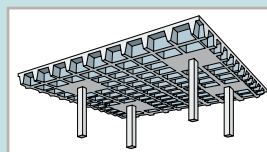
#### Markets:

- ✓ Vibration critical projects
- ✓ Hospitals
- ✓ Laboratories

Ribbed slab



Waffle slab



#### Benefits:

- ✓ Flexible
- ✓ Relatively light, therefore less foundation costs
- ✓ Speed
- ✓ Fairly slim floor depths
- ✓ Robustness
- ✓ Excellent vibration characteristics
- ✓ Thermal mass
- ✓ Good services integration
- ✓ Durable finishes
- ✓ Fire resistance

### Cost/whole life cost/value

Ribbed and waffle slabs normally have good surface finish to the soffit, allowing exposed soffits to be used in the final building. This allows the use of the thermal mass of the building in the design of the HVAC requirements, particularly as the soffit surface area of the slab is greater than a flat slab, increasing the building's energy efficiency.

### Speed on site

This is a slower form of construction than flat slabs, but where table forms can be used, this increases the speed.

Where partitions need to be sealed, acoustically or for fire, up to the soffit, ribbed and waffle slabs take longer on site. Lightweight floor blocks can be used as permanent formwork, which give a flat soffit, although these take away some of the benefits of the lighter-weight slab design. If partition locations are known, the moulds may be omitted on these lines.

### Mechanical and electrical services

Holes should be located in the topping slab rather than the ribs where possible. If the holes are greater than the space between ribs, then the holes should be trimmed with similar depth ribs. Post-construction holes can be located in the topping slab.

### Health and safety

Modern formwork systems can incorporate all edge protection and provide a robust working platform.



# Beams and slabs

**Beam and slab construction involves the use of one or two way spanning slabs onto beams spanning in one or two directions. The beams can be wide and flat or narrow and deep, depending on the structure's requirements. Beams tend to span between columns or walls and can be simply supported or continuous.**

This form of construction is commonly used for irregular grids and long spans, where flat slabs are unsuitable. It is used in retail and storage where the ability to form large voids or support high imposed loads is paramount. It is also used for transferring columns, walls or heavy point loads to columns or walls below.

It is not a fast method of construction as formwork tends to be labour intensive.

## Points to Note

### Design

This is a very common form of construction and as such is well covered in standard codes and guidance.

Beams can be designed as either L or T beams using the slab as a flange.

### Construction

Where possible the formwork and falsework should be reused, so standard beam sizes should be specified if possible. Beam reinforcement can be prefabricated and craned into place. Slabs tend to be lightly reinforced and can normally be reinforced with standard mesh. Slabs are often constructed using precast or hollowcore concrete.

### Lead times

Fast lead times as formwork tends to be made on site.

### Procurement

All concrete frame contractors, and indeed general builders, are able to do this type of work.

### Speed on site

Slow on site due to time required for formwork and fixing the reinforcement for the beams.

### Mechanical and electrical services

Wide band beams can have less effect on the horizontal distribution of the M&E services than deep beams which tend to be more difficult to negotiate, particularly if spanning in both directions. Any holes put into the web of the beam to ease the passage of the services must be coordinated.

Vertical distribution of services can be located anywhere in the slab zone, but holes through beams need to be designed into the structure at an early stage.

### Health and safety

Most of the work is undertaken on site; therefore care is needed with all operations. Formwork should include all guard rails.

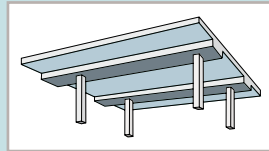
## ✓ CHECKLIST

### Beams and slabs

#### Markets:

- ✓ Transfer structures
- ✓ Heavily loaded slabs
- ✓ Long spans unsuitable for flat slabs

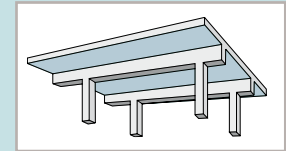
#### Band beam and slab



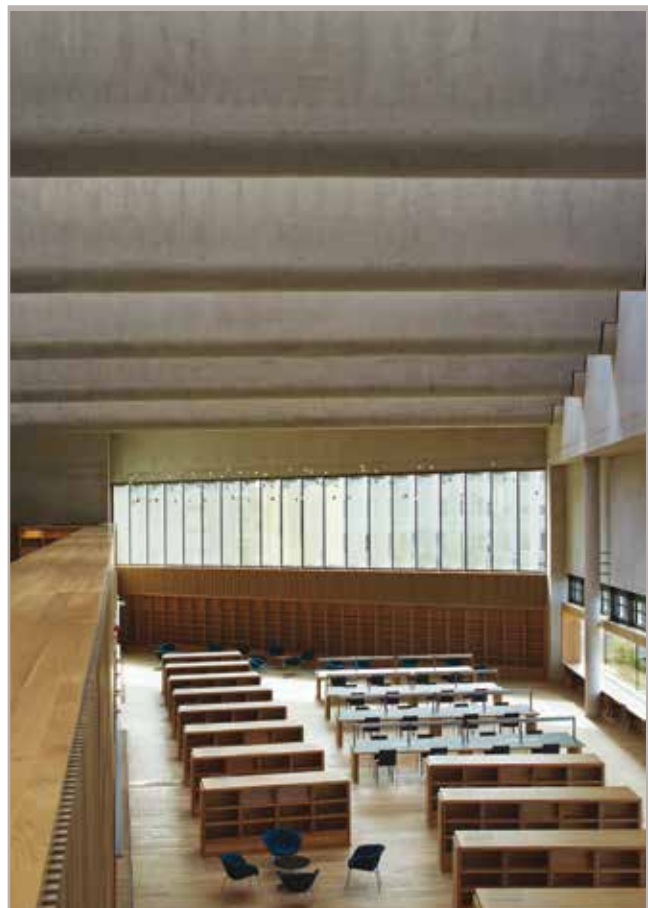
#### Benefits:

- ✓ Flexibility
- ✓ Sound control
- ✓ Fire resistance
- ✓ Robustness
- ✓ Thermal mass

#### Deep beam and slab





Beam and slab construction at DLR Lexicon. © VIEW

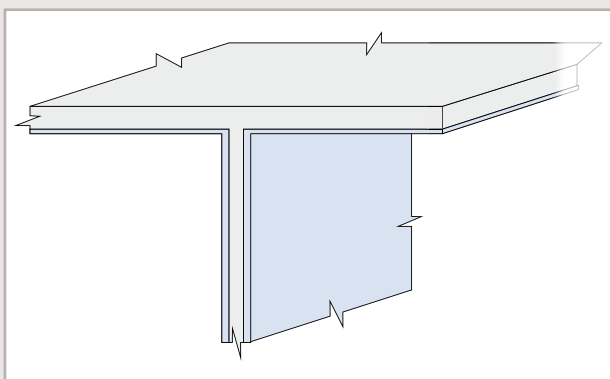


# Hybrid concrete construction

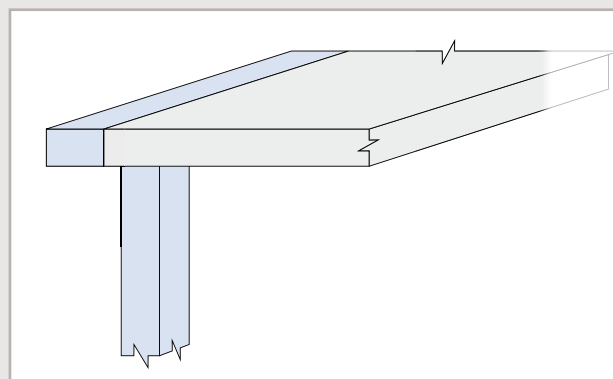
Hybrid concrete construction (HCC) makes use of precast and in-situ concrete together, combining the benefits of both to give a robust, durable construction which is fast on site, with an excellent finish. There are many different forms of HCC as different parts of the structure can be precast. Further information can be found in The Concrete Centre's *Hybrid Concrete Construction* [10].

Key	
	Precast
	In-situ

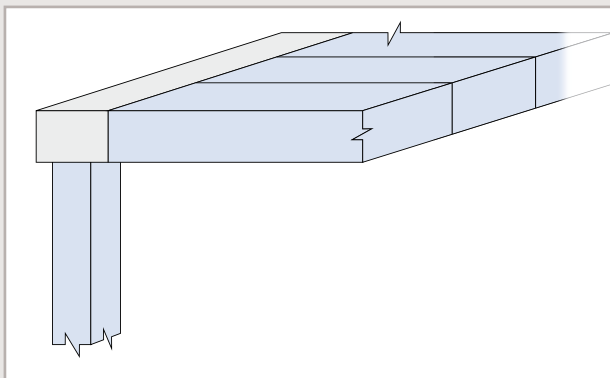
## Some possible hybrid concrete construction options.



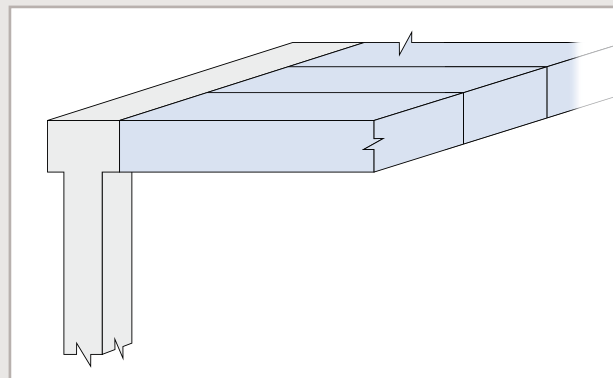
**Option 1:** Precast twin wall and lattice girder slab with in-situ infill and topping



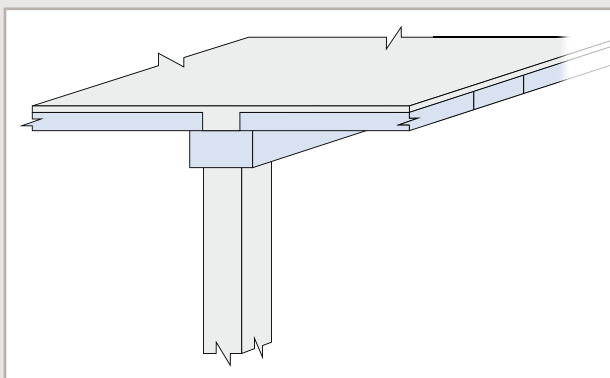
**Option 2:** Precast columns and edge beams with in-situ floor slab



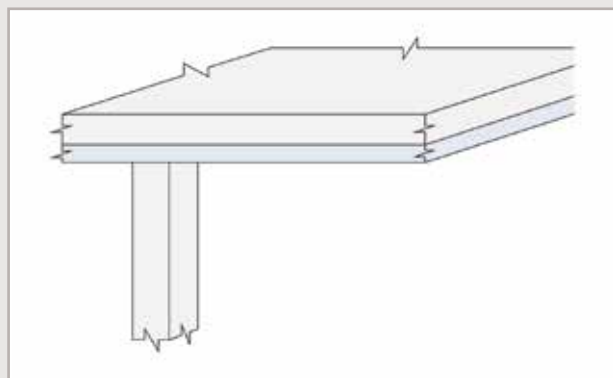
**Option 3:** Precast columns and floor units with cast in-situ beams



**Option 4:** Cast in-situ columns and beams with precast floor units



**Option 5:** Cast in-situ columns and floor topping with precast beams and floor units



**Option 6:** In-situ topping with lattice plank

## Points to Note

### Design

HCC can be designed as a normal reinforced concrete building, with full composite action between in-situ and precast elements. The construction phase needs to be designed, as one of the load cases is normally precast concrete elements supporting the weight of wet in-situ concrete. An additional stage may be considered if de-propping happens before the in-situ concrete develops its design strength. Precast elements should be repetitive, as mould costs are a significant factor. For non-standard areas, insitu concrete could be used instead, or layout altered to allow a standard form.

### Construction

Full coordination of the services through the building needs to take place early in the design process, as they need to be incorporated into precast elements. Also items frequently sorted out on site must be resolved before the project gets to site, allowing faster and safer construction.

### Lead times

Depending on the precast elements of the construction up to twenty weeks lead in time can be necessary. However rapid progress of in-situ elements can be made, with substructure often completed in this period. The design should be fully coordinated prior to the precast elements being manufactured if coordination affects the precast elements.

### Procurement

Since a standardised layout allows the full benefits to be realised, use of HCC should be considered from design concept stage.

A lead frame contractor (usually a concrete frame contractor) should be appointed early together with specialist supplier(s) of the precast elements. This will provide the best advice to the design team and hence the best finished building.

### Cost/whole life cost/value

Initial HCC costs vary, depending on quality of finish required and the extent of repetition of precast units.

HCC can provide the best value building, as the procurement process should allow for cooperation between parties to provide best value for client's requirements.

### Speed on site

One of the benefits of HCC is speed. A leading contractor is using HCC to reduce time on the site, for a typical concrete framed building, by 50%.

### Mechanical and electrical services

M&E services can be integrated into precast elements, and need to be fully coordinated. Thermal mass can be used to reduce energy consumption of the building in comparison to other similar sized buildings.

### Health and safety

HCC is a modern method of construction, with much work done in the factory, where activities are easier to control. Where precast slab units are used (the majority of cases) the working platform is provided by the slab, giving less danger of a fall from height.

## ✓ CHECKLIST

### Hybrid concrete construction

#### Markets:

- ✓ All: particularly suited to offices – bespoke and speculative
- ✓ Schools
- ✓ Car parks
- ✓ Retail
- ✓ Sports stadia

#### Benefits:

- ✓ Cost
- ✓ Speed
- ✓ Accuracy for prefabricated elements
- ✓ Sound control
- ✓ Fire resistance
- ✓ Robustness
- ✓ Thermal mass
- ✓ Durability
- ✓ High quality finishes
- ✓ Safety

The Francis Crick Institute, London used lattice girder slabs with an in-situ concrete topping to speed construction. © Alamy



# Precast concrete

Precast concrete can form all types of structures, from cellular type construction such as crosswall where wall and slabs are precast, to 'stick' frame construction with columns, beams and slabs. Precast concrete is particularly suited to uses where either speed on site or a fine fairfaced concrete finish is required. A high degree of repetition is advisable, as the cost of the mould required for each element reduces the more the mould is used.

Precast concrete can also be used as elements within a building. For instance, precast footings or stairs can be used whether the main frame is precast concrete or not.

The use of precast concrete at the Gloucester Docks project meant that the car park element of the project was erected in just seven weeks. The car park is a 15.6m clear span with a circular ramp structure at each end. Courtesy of Composite.





## Points to Note

### Design

Grids and layouts should be as repetitive as possible. Precasters can give advice at an early stage to achieve the most economic layouts.

Precast concrete is normally manufactured from higher strength concrete and the design can take advantage of this.

Junctions between the precast elements need to be designed. This can be done by the specialist subcontractor, or they can give guidance to the designer. Code requirements to protect against progressive collapse are fully met by use of tie bars through junctions, bolted details or proprietary jointing systems.

Load bearing precast concrete cladding can also be used as a precast frame ensuring the building becomes weather tight as quickly as possible, allowing finishing works to start early.

### Construction

The use of precast concrete can be helpful on a tight site provided access is not a problem. Precast concrete elements can be craned into place from a lorry, eliminating any need for storage areas for reinforcement or shutters.

Coordination between the specialist subcontractor and other subcontractors is vital to ensure the best is achieved from precast. The specialist subcontractor should be appointed as soon as possible to enable both coordination and buildability aspects to be fully integrated into the precast design.

Some in-situ stitching is required at joints, but normally only involves grouting up connections.

The size of the largest piece of precast concrete normally dictates the size of the crane, so similar weight elements should be used if possible. The contractor should beware of the largest lift requiring the largest reach and access.

### Lead times

Lead times are approximately four months for structural precast frames. This includes preparing all drawings for product manufacture and coordinating with other subcontractors. Lead times for simple standard elements, such as stair flights or hollowcore slabs, are significantly less.

### Procurement

The trade association, British Precast and its specialist bodies the Architectural and Structural Precast Association (ASPA) and the Precast Flooring Federation (PFF) holds lists of specialist precast subcontractors and their specialities.

Some standard precast frames, such as those for car parks, are frequently procured as a "turn-key" project where the design, detailing and erection are carried out by the specialist precaster.

### Cost/whole life cost/value

With the use of durable finished concrete, maintenance for precast concrete buildings is kept to a minimum, providing excellent value for the whole life costs.

The thermal mass of the building can be used as long as it is exposed (i.e. if suspended ceilings are not provided) so that the long term costs of heating and cooling the building are reduced.

## ✓ CHECKLIST

### Precast concrete

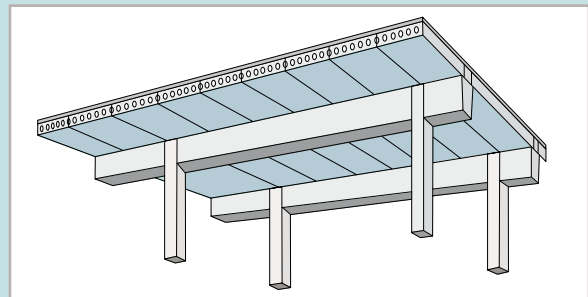
#### Markets:

- ✓ Residential
- ✓ Hotels
- ✓ Car parks
- ✓ Shopping centres
- ✓ Commercial
- ✓ Student accommodation
- ✓ Prisons

#### Benefits:

- ✓ Speed on site
- ✓ Accuracy for prefabricated elements
- ✓ Sound control
- ✓ Fire resistance
- ✓ Robustness
- ✓ Thermal mass
- ✓ Durable finishes
- ✓ Safety
- ✓ Reduced risk
- ✓ Minimal deliveries

#### Precast concrete



### Speed on site

Precast concrete frames are very quick to erect on site. Speed is one of the main benefits of using precast concrete.

### Mechanical and electrical services

Mechanical services can be integrated into precast elements. Systems can pass heating or cooling through precast concrete floor slabs, allowing the thermal mass of the concrete to act as a storage heater or cooler. The precast option should be integrated into the design at concept stage to allow the full benefits of servicing the building to be realised.

Using the thermal mass of the building reduces both service requirements and size of plant.

Electrical services can be integrated into the design of precast elements as conduits can be cast into the elements in the factory.

### Health and safety

As the fabrication of the precast elements takes place in a factory setting, health and safety factors on site are much reduced.

# Crosswall

**Crosswall is a type of precast system that produces cellular construction suitable for hotels, student accommodation and affordable housing.**

The system comprises precast walls and slabs, together with stairs which make up the full requirements for a robust stable solution. The concrete finish tends to require some form of finishing: plaster, plasterboard or paint.

External elevations can be precast concrete with external finishes applied on site or can be in the form of sandwich panels where the external wall finishes form part of the elevation panel.

East London University used crosswall for its student accommodation in London Docklands. Courtesy of Bell and Webster.



## Points to Note

### Design

The design of crosswall systems is normally carried out by the precast specialist, but the basics are fairly simple. All the precast walls are loadbearing, including, normally, the elevations. As with all precast solutions, the grids should be kept as regular as possible, but there is some flexibility with the dimensions.

Walls can be thinner than those normally specified for in-situ construction, with 150mm being a common thickness. This can save area or provide more useable space. The individual walls and slabs should be kept to a maximum dimension of 11m x 4m as this is the size that can be easily transported to site. Although crosswall is normally used for rectangular blocks, it is possible to incorporate non-standard grids and more complicated arrangements.

Crosswall systems can incorporate sandwich panels for the elevations. These are precast wall elements which incorporate the insulation and external wall finishes, and frequently have windows already installed before coming to site. This can speed up the erection of the building significantly and avoid the need for external scaffolding.

The detailing of the crosswall systems ensures that all the tying requirements are fully met. Reinforcement hoop ties are locked in place with a rebar threaded through hoops. The interlock can be checked before the connection is grouted up.

Information about the design of crosswall systems can be found in The Concrete Centre's publication *Design Guide for Cellular Residential Structures*.

### Construction

The crosswall system is fast on site as the precast elements are lifted off the lorry directly into location in the building. This eliminates double handling on site reducing crane time and speeding the construction. The precast walls are located into position on site and propped. The slabs are then lifted into position and fixed onto the walls. When lined and levelled, the joints between the elements are grouted up.

Normally the only crane required on site for the erection of the crosswall system is a mobile crane.

### Lead times

The lead times for crosswall construction should allow for the final design and detailing of the precast concrete together with the manufacture of the components. This means that there is a minimum lead-in period of 12 weeks, but this might be increased if sandwich panels are specified or the coordination of the M&E services is more complicated than usual.

### Procurement

British Precast and its product association, The Architectural and Structural Precast Association, hold a list of crosswall manufacturers.

A crosswall construction can be procured as a "turn-key" project where the design, detailing and erection are carried out by the specialist precaster.

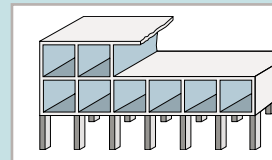
### ✓ CHECKLIST

#### Crosswall

##### Markets:

- ✓ Residential
- ✓ Housing
- ✓ Hotel
- ✓ Hostel
- ✓ Student accommodation
- ✓ Prisons

Crosswall



##### Benefits:

- ✓ Speed
- ✓ Accuracy for prefabricated elements
- ✓ Sound control
- ✓ Fire resistance
- ✓ Robustness
- ✓ Thermal mass
- ✓ Durable finishes
- ✓ Safety
- ✓ Reduced risk
- ✓ Minimal deliveries

### Cost/whole-life value

As the concrete provides a robust, durable finish, the maintenance of the system is kept to a minimum, providing excellent whole life costs.

The thermal mass of the building can be used if included in the design, providing a lower requirement for heating and cooling the building and saving on both the initial and ongoing M&E costs.

Crosswall is normally used for residential buildings, student accommodation, hotels and the like. Here the benefits of the concrete frame can be realised for the occupants, providing a quieter atmosphere with less disruption from neighbouring properties.

### Speed on site

Speed on site is one of the main benefits of using the crosswall system.

### Mechanical and electrical services

The electrical services can be installed within the precast and all the holes for the mechanical services should be planned out and incorporated within the design and detailing of the precast work.

### Health and safety

With crosswall, much of the work is taken off site to be done in a factory, which makes it inherently safer than in-situ construction. The specialist contractor should follow the Code of Practice: *The safe installation of precast concrete flooring and associated components*. This publication provides guidance on the safe manufacture and construction of precast concrete components.

# Concretes for framed buildings

**In today's modern world of concrete, performance parameters are no longer solely restricted to the material's 28 day compressive strength. Beyond strength and durability, there may be other properties of concrete that are desirable on any given project.**

These innovations may include:

- High ultimate strengths ( $>70 \text{ N/mm}^2$ )
- High early strengths
- Controlled low strength
- High elastic modulus
- High tensile strength
- High density
- Low creep and shrinkage
- Low heat of hydration
- Pumpability
- Constructability and placeability
- Durability/Serviceability
  - Water, chloride and oxygen diffusion
  - Sulfate and aggressive chemical attack
  - Abrasion resistance
  - Freeze-thaw resistance
  - Resistance to high intensity fire and extremes of temperature

One or several of these performance parameters may be specified by the concrete structure's designer. Durability and serviceability are the most frequently specified criteria. Most standards and codes of practice contain minimum performance levels. However, in today's high-rise concrete frame sector, pumpability and constructability are often controlling parameters which determine mix design.

## High Performance Concretes

There are no definitive rules for the design of high performance concretes (HPCs) but, generally speaking, they usually contain low water contents and relatively high powder contents. For example, the high-rise pumping of concrete will require mix designs containing an excess volume of paste, with low water and air contents.

Until recent years, superplasticisers did not exhibit sufficient water reduction capabilities and mixes often had to contain very high levels of Portland cement. The development of polycarboxylate based admixtures has significantly changed this, enabling the boundaries of HPCs to be expanded.

Cement replacement materials, such as fly ash and ground granulated blastfurnace slag (GGBS) have been used in concretes for a long time, and their inclusion is nearly always required in HPCs. Other ultra-fine materials are frequently included, such as microsilica and limestone powder, to provide ternary and even quaternary blends of powder content. It should be stressed that HPCs of good and consistent quality are best produced in wet-batch, pan mixer type plants.

The consistency of HPCs are generally of a high workability and flow, enabling faster and easier pumping and placement of the concrete, reducing labour and producing better off-form finishes.



Exposed visual concrete at the Angel Building, London.  
Courtesy of AHMM Architects.

## Benefits of high performance concretes

For	Benefits
Building owner	<ul style="list-style-type: none"> <li>✓ Less maintenance</li> <li>✓ Longer service life</li> <li>✓ More durable</li> <li>✓ Smaller column sizes</li> </ul>
Designer	<ul style="list-style-type: none"> <li>✓ Use of higher strength concrete</li> <li>✓ More efficient use of concrete</li> <li>✓ Better finishes</li> </ul>
Contractor	<ul style="list-style-type: none"> <li>✓ Faster placement of concrete</li> <li>✓ Earlier stripping of formwork</li> <li>✓ Reduced labour</li> <li>✓ Less making good</li> </ul>



## Flowing and self-compacting concrete

The third generation of plasticisers are based upon polycarboxylate technology and are powerful admixtures which enable the consistent production of flowing concrete by ready-mixed concrete producers for supply to projects. Major projects such as the Channel Tunnel Rail Link and Canary Wharf have extensively used flowing concretes in their construction.

The development of self-compacting concrete (SCC) was a significant development for in-situ concrete construction. SCC is a natural progression of the concept of flowing concrete. SCC requires no vibration. It will flow under its own momentum for horizontal distances of between 10 and 15 metres. With a high content of fillers derived from waste materials (fly ash, GGBS, microsilica, limestone powder and/or granite powder, etc.) and no need for vibration, it is more beneficial than conventional concrete from the aspects of health, safety and the environment.

Flowing concretes and SCCs generally have high slumps (>220 mm) and spread flows (>600 mm).

### Flowing concretes

In order to maintain cohesion and reduce bleed, sand contents of between 45 and 50% (dependent upon sand gradings) are incorporated into the mix.

Powder contents are normally > 380 kg/m<sup>3</sup> and often include replacement materials such as fly ash, or ggbs in order to reduce the cost of the powder component and, in the case of fly ash, to further improve mix cohesion. Relatively low water contents are required, achieved by including a polycarboxylate based superplasticiser, which also imparts the required high workability.

A benefit accruing from using this type of admixture is the high water reduction capability, which enables high strength flowing concretes to be designed at moderate cement contents. e.g., a C40/50 strength class flowing concrete can be designed with only 380 kg/m<sup>3</sup> of cement.

### Self-compacting concrete

SCC contains relatively high powder contents. This is required to eliminate bleed (segregation) of the concrete and maintain its cohesion.

Powder (or binder) contents are usually of the order 500 to 550 kg/m<sup>3</sup>, with sand contents between 48 and 55%. Binary, ternary and even quaternary blends of Portland cement (CEM I) and filler materials comprise the binder content. It is possible, with judicious mix design, to produce SCCs of up to 100 MPa characteristic cube strength that contain less than 400 kg/m<sup>3</sup> of CEM I. Water contents are normally within the range of 170 to 190 litres/m<sup>3</sup>. Coarse aggregate sizes may be up to 20 mm maximum, although the optimum is 10 to 14 mm.

A polycarboxylate superplasticiser is normally included in the mix. A second admixture (a viscosity modifier) is frequently added to improve cohesion and reduce bleed.

When placing SCCs, the material should not be allowed to 'free-fall', since this will entrap air in the concrete which will not expel itself and, consequently, leave unsightly blemishes on struck surfaces. Similarly, when casting walls or columns with SCC, best results are obtained when the material is pumped through the bottom of the forms and not allowed to drop through the reinforcement.

The unformed surface can only accept a brushed finish, not a power floated finish.

For more information on SCC technology visit [www.efnarc.org](http://www.efnarc.org).

### Cost Benefits Analysis

The costs of mix designs of flowing concrete are approximately 10% higher, and SCCs are approximately 20 to 50% higher in cost, than those of concretes with identical strength and an S2 or S3 consistency (50 to 150 mm slump) but reduce noise and H&S issues due to vibration. The true cost benefit of using either flowing concrete or SCC in a structure can only be quantified by adopting a holistic approach to estimating and costing.

Possible Cost Increases	Possible Cost Savings
1. Cost of concrete/m <sup>3</sup> .	1. Faster pumping and placing of concrete.
2. Improvement of formwork jointing to prevent grout loss (not an issue when using proprietary formwork systems).	2. Earlier finishing of concrete.
3. Stiffening of some formwork to resist formwork pressure.	3. Significant reduction in labour to place concrete.
	4. Elimination (for SCCs) or reduced use (for flowing concretes) of vibrators and resultant site noise pollution – No HSE problems with vibration.
	5. Can produce better off-form finishes.
	6. Less wear and tear on concrete pumps.
	7. Higher early strengths, reducing stripping time and increasing productivity.
	8. Higher ultimate strengths, possibly enabling more efficient structural design and hence more lettable floor area for the client.
	9. Possible longer working hours, due to less noise.

## Concretes for cores

Slipform and jumpform techniques are fast and efficient systems for constructing cores and shafts in high rise structures. The concrete requirements of the systems are, however, quite different from each other.

### Slipform Construction

In slipform construction, the platform of formwork is continuously raised by hydraulic jacks, at a rate of approximately 300mm per hour, with fresh concrete being placed in even layers into the forms. A continuous supply of concrete is required, fluid enough for rapid placement. Open time must be sufficient for adjoining layers to meld together and then undergo a relatively speedy combination of aggregate locking and stiffening, in order to allow forms to be raised without bulging or tearing the concrete.

Factors that affect the execution of slipform construction are primarily related to heat generation and absorption within the structure. These are:

- Variations in ambient temperature over the casting cycle and the seasons.
- The heat of hydration of previously poured, underlying layers, which accelerates the setting times of the freshly placed concrete above.
- Thermal gradients within the structure, caused by varying wall thicknesses.
- Thermal gradients within the structure, caused by solar radiation (south facing walls of a project get hotter than north facing ones).
- Thermal gradients within the structure, created by openings in the walls for lift shaft and stairwell access.

From the above, it may be seen that the supplier of concrete to a slipform project will have to be able to supply concretes of the required characteristic strength but with a very wide range of setting times. This spectrum of mix designs can range from a plain CEM I, with no retarding admixtures, to a concrete with high levels of cement replacement (fly ash or ggbs) with retarder levels of several hours. Selecting the type of concrete used during various stages of the pour should be done by the contractor together with the concrete producer. Coarse aggregate should preferably be of the crushed rock type, to provide better aggregate locking characteristics.

### Jump form Construction

From the point of view of both contractor and concrete supplier, concrete for jump form construction is much simpler than for slipforming. In jump form construction, floor heights of cores are cast in a single operation. Forms are then independently raised to the next level and fixed by an anchoring system to the previously cast level of concrete below.

Because of the need to fix the formwork support to concrete that has only been cast the previous day, high early age strength (15 N/mm<sup>2</sup> at 15 hours) is required. This is normally achieved by the use of additions in the concrete.

### High Rise Construction

In order to be pumped up to a high level, normal concretes need modifying with superplasticisers and higher powder contents. This



The Shard, London features a high-performance concrete core, which utilised an innovative use of top-down construction with concrete that achieved 30 MPa cube strength within just 24 hours.

normally leads to higher strength concretes being produced, just to provide a pumpable mix. If this is the case, the designer can use the high strengths (C40/50 and above) within the design to achieve the most economical design. When used in columns this will result in more lettable, or useable floor space. When used in slabs, the increased strength also gives more stiffness, so a slab thickness governed by deflection may be able to be reduced.

# Cost and Programme

**Cost and programme are two major criteria in assessing design and construction alternatives and construction professionals require scheme designs in order to inform their decisions. Cost studies are also useful in giving a detailed and rigorous assessment of how structural frame choice can affect the costs and programme implications of other items, such as cladding, internal planning, services, fit-out, etc.**

Three complete cost model studies were commissioned by The Concrete Centre in order to compare the costs of constructing three types of buildings – offices, hospitals and schools – with different structural solutions. For the comprehensive analysis of the original studies please refer to the *Cost Model Study – Commercial Buildings*, *Cost Model Study – Hospitals* and *Cost Model Study – Schools* available from [www.concretecentre.com/publications](http://www.concretecentre.com/publications). The cost data for the office Cost Model Study was updated in 2013 and is data is available in the publication entitled *Office Cost Study* [2], also available from the website.

The cost model studies looked at two office buildings, one a three storey office in an out-of-town business park and the other a six storey city centre office building. The hospital cost model study considered an acute hospital and a community hospital. The school cost model study concerned a relocated secondary school. Typical structural frames were studied including flat slabs, post-tensioned slabs, composite steel frames and hybrid frames.

## Costs

As could be expected, there was not a single solution that was the cheapest option for all the different types of building. But the concrete frames performed very well, as can be seen from the table. The cost performance of concrete was maintained in the 2013 update.

Table 1: Cost model studies: summary of costs

Building	Cheapest concrete frame	Cost (£/m <sup>2</sup> )	Cheapest steel frame	Cost (£/m <sup>2</sup> )	Cost benefit for concrete option
Office: 3 storey	Flat slab	1406	Composite	1422	1.1%
Office: 6 storey	Flat slab	1593	Composite	1613	1.3%
Office: 6 storey long span option	PT band beam and slab	1636	Long span composite	1643	0.4%
Hospital: Acute care	PT flat slab	2088	Steel and hollowcore	2171	4.0%
Hospital: community	PT flat slab	1871	Composite	1890	1.0%
School	PT flat slab	1459	Steel and hollowcore	1487	1.9%

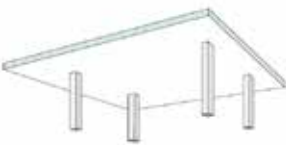

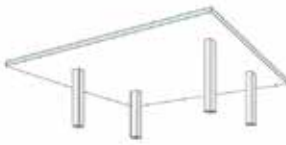





The costs included all the fittings and fit-out, together with the M&E costs. The M&E and fit-out costs were kept the same across the different structural options. It would be possible to reduce further the costs of the concrete frame options by using the concrete itself as the final finish and by using the thermal mass of the concrete frame to reduce the requirements for servicing the buildings.

## Programme

Concrete can be built quickly by the use of modern formwork systems and precast elements. The cost model studies included programmes for each of the options. Since the cost model studies were done in 2007/08 the construction of concrete frames has developed and even faster times would now be expected. The table shows the study findings and gives the overall project time including the procurement and lead-in periods.

Table 2: Cost model studies: summary of programme

Building	Quickest concrete frame	Weeks	Quickest steel frame	Weeks
Office: 3 storey	Flat slab	64	Composite	70
Office: 6 storey	PT flat slab	82	Steel and hollowcore	91
Office: 6 storey long span option	PT band beam and slab	83	Long span composite	95
Hospital: Acute care	PT flat slab	151	Steel and hollowcore	147
Hospital: community	In situ and hollowcore	105	Steel and hollowcore	100
School	PT flat slab	83	Composite	88

Short-span options			Long-span options
Option 1 – Flat Slab	Option 2 – Composite	Option 3 – PT Flat Slab	Option 7 – PT Band Beams
			
Reinforced in-situ concrete flat slab and columns	Steel beams and metal decking, acting compositely with in-situ concrete floor slabs. Steel columns	Post-tensioned in-situ concrete flat slab and reinforced in-situ concrete columns	Post-tensioned in-situ concrete flat slab and band beams with reinforced in-situ concrete columns
Option 4 – Steel + Hollowcore	Option 5 – In-situ + Hollowcore	Option 6 – Slimdek	Option 8 – Long-Span Composite
			
Steel beams acting compositely with precast concrete hollowcore floor slabs. Steel columns	Reinforced in-situ concrete beams and columns with precast concrete hollowcore floor slabs	Slimdek system comprising asymmetric beams and metal decking, acting compositely with in-situ concrete floor slabs. Steel columns	Long-span cellular steel beams and metal decking, both acting compositely with in-situ concrete floor slab. Steel columns

# Sustainability

**Sustainability is a key design outcome for many clients. Concrete's flexibility offers many opportunities for designers to influence the environmental, economic and social credentials of their projects, including performance credentials such as fire, durability, acoustics and adaptability.**

The UK government is committed to reducing its CO<sub>2</sub> emissions to 80% of 1990 levels by 2050. Data from the Department of Energy and Climate Change (DECC), estimates that 55% of UK CO<sub>2</sub> emissions are related to buildings. However, only 10% of this can be influenced by the construction process, with the remainder being related to the operational energy of residential (27%) and non-residential (18%) buildings [12].

Through the use of concrete's inherent performance benefits – together with the ability to use concrete as a finish and avoid the need for additional materials – project teams can meet and exceed client's expectations on sustainability.

For more information on the sustainability credentials of concrete and cement please refer to *Specifying Sustainable Concrete* published by The Concrete Centre [13].

The Concrete Centre has also published a publication on how to use concrete more efficiently and this document, *Material Efficiency*, can be downloaded from [www.concretecentre.com](http://www.concretecentre.com).

Sites of mineral extraction have a proven history of restoration and enhancing biodiversity. Over 700 of the UK's 4,000 SSSIs have their origins in quarries.



## Sustainable Production

Concrete is the ultimate 'local material'. Material supply is UK based, we are to all intents and purposes self sufficient in the raw materials needed to produce concrete for the foreseeable future:

- 99.9% of all aggregates used in the UK are UK in origin
- 90% of Ordinary Portland Cement produced in the UK (10% imported due to international companies)
- 100% of UK-produced reinforcement is produced from UK-sourced scrap steel
- 100% admixtures produced in UK
- 100% fly ash produced in the UK
- 90% GGBS produced in the UK.

Typically, raw materials for concrete are sourced locally to the concrete producer's plant, and plants are local to the construction site. This:

- Significantly reduces transportation environmental, economic and social impacts – 80% of all aggregates are used within 30 miles of extraction
- Supports local economy
- Supports local jobs
- Does not transport environmental impacts to other countries that may have lower levels of environmental protection legislation.

Concrete production also uses materials that would otherwise be sent to landfill:

- Concrete uses fly ash and GGBS as cement replacements. These materials are by-products of other industries
- The concrete industry requires high temperatures for production, primarily in cement manufacture, and this is an opportunity to safely burn alternative combustible materials as fuel instead of non-renewable fossil fuels.
- Concrete production uses 107 times more waste than it produces.

In 2008, the concrete industry embarked on a sustainable construction strategy. Since then the industry has made significant progress towards meeting its strategy commitments. The industry reports on its progress against these targets every year and the latest report can be downloaded from [www.sustainableconcrete.org.uk](http://www.sustainableconcrete.org.uk).



## Sustainability in Use

### Thermal mass

Concrete's inherent thermal mass can be used to reduce a building's cooling energy needs, helping in turn to cut operating emissions and enhance overall sustainability.

The use of thermal mass to optimise building performance centres on the principle of Fabric Energy Storage (FES), which allows concrete floor slabs to absorb unwanted heat, helping stabilise the internal temperature and cut the CO<sub>2</sub> emissions associated with mechanical cooling. This is achieved either passively or in combination with a more active approach such as mechanical ventilation and/or chilled water pipes embedded in the slab, which enhance performance. Using floors to provide cooling makes good sense, as they typically provide the greatest source of thermal mass in a building.

The way FES works is quite simple: Providing the soffit is left exposed, thermal mass in the floor slab will absorb and store excess heat during the day, which can then be purged using the cool night air to ventilate the building. The main way in which concrete soffits absorb heat is by radiation from adjacent people, objects and surfaces at a higher temperature, all of which will naturally radiate heat to the comparatively cool soffit above. This beneficial radiant cooling effect continues throughout the

day even though a significant amount of heat may be absorbed. This is a consequence of the thermal mass (i.e. heat capacity) provided by the slab, which ensures the surface temperature increases very little across the day and a useful temperature difference between soffit and occupants is maintained.

Floor slabs also provide some convective cooling i.e. to air that comes into contact with the concrete. This is more significant where floors form part of a mechanical ventilation system. In addition to reducing a building's cooling, thermal mass can also delay its peak by around six hours, which in an office environment, will usefully occur in the early evening when the occupants have left for the day.

The amount of cooling provided is largely determined by the level of design sophistication applied. A simple, passive system that uses natural ventilation to cool the slab at night will provide around 20 W/m<sup>2</sup> of cooling, whilst more active systems that make use of mechanical ventilation and/or water cooling can deliver up to 65 W/m<sup>2</sup>; sufficient to meet most cooling needs.

For more information on the use of thermal mass in buildings, see The Concrete Centre publication *Concrete Floor Solutions for Passive and Active Cooling*.

Five Pancras Square, London, achieves BREEAM Outstanding, the highest standard of environmental sustainability for a major office development. © VIEW



### Healthy working and living environment

Buildings should be safe, pleasant and healthy places in which to live and work. Concrete is inert; it does not give off any chemicals or gases; it has no need of toxic preservatives, nor does it need additional corrosion or fire protection. Research confirms that concrete with natural ventilation is an excellent strategy to help reduce Sick Building Syndrome (SBS) [13].

The look and feel of a well-designed and aesthetically pleasing building is known to affect the mood, wellbeing and performance of users, and project a positive image for organisations. Uplifting architecture, often involving the use of exciting, structurally efficient exposed soffits, columns and walls, can all add to a building's character and ambience. This provides an alternative design approach which can reduce initial cost, maintenance and delay refurbishment.

Sound pollution and nuisance is a major problem, especially in residential buildings, with the trend for high density, high rise, hard flooring and noisy brownfield locations. Independent testing has confirmed that the inherent mass of concrete means that, to meet Part E of the Building Regulations, additional finishes to walls and floors are minimised or even eliminated [3].

### Robustness/fire/terrorism

Concrete is inherently robust, capable of withstanding loads of up to 100 MPa. The US Federal study into the 2001 attack on the Pentagon, Washington DC, stated that this concrete building's structural resilience provided vital resistance to its collapse.

Concrete is inherently incombustible, and, unlike some other materials, normally requires no added fire protection. This avoids the delays and disruptions of follow-on trades caused by site applied protection, or repair on site of damaged off-site applied protection. Concrete's fire protection is provided at no extra cost. The inherent fire resistance results in concrete often performing in excess of design requirements for occupant safety. This benefits the building owner as repairs and the period before reuse following a fire is minimised, as are any potential repairs to the structure.

## Sustainability at End of Life

Concrete can be part of a virtuous cycle, provided lifecycle impacts are considered from day one of the design stage. When a building, or part of a building, reaches the end of its functional life, the most effective solution is to refurbish. Failing that, value should be recovered through recycling or reuse of components. Only if there is no other alternative should disposal be considered. With concrete, there is no need for disposal – almost everything can be recovered, including reinforcement, which can be returned to the scrap metal resource from which it was made.

Once a concrete building has reached the end of its useful life, up to 95% of even the most heavily reinforced concrete can be recycled, commonly for use in road and runway sub-bases. Recycled aggregates account for 25% of the UK's aggregates supply and that proportion is set to grow in the years to come. Reinforcement can be recycled and remade into new reinforcement. UK-produced reinforcement is made from 100% scrap steel, with reinforcement further recycled at the end of its first, second, third life etc.

# Summary

**A concrete frame can improve the overall performance of your building. There are many forms of fast, efficient and effective concrete frames.**

- Flat slabs are a cost effective form of construction, providing flat soffits which will speed up follow-on trades such as M&E and internal partitions.
- Flat slabs are a slim form of construction, reducing the overall height of the building.
- Ribbed and waffle slabs are excellent for areas where vibration particularly needs to be controlled.
- Beams and slabs are a very flexible common form of construction.
- Post-tensioning concrete increases its structural efficiency, allowing it to span longer distances or reducing the depth of section required.
- Hybrid concrete construction is a fast form of construction, bringing together the finish quality of precast with the flexibility and mouldability of insitu concrete.
- Precast concrete allows fast construction on site with minimal waste and provides excellent factory quality finishes requiring little or no finishing on site.
- New high performance concretes have been developed which can bring benefits to the building owner, the designer and the contractor. High performance concretes tend to be more durable and easy to lay.
- Concrete producers can supply concretes to meet the requirements of all the construction forms presented in this publication.
- Concrete is a local product, with low embodied energy, and is fully recyclable at the end of its life.
- Concrete is durable and requires little or no maintenance. It does not burn and is not susceptible to rot.
- Concrete's thermal mass can be used to reduce dramatically the energy required to heat or cool a building, leading to lower operational costs.



The Beetham Tower, Holloway Circus in Birmingham used post-tensioned concrete flat slabs to give a slim structural zone.

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To download or access many of these publications visit [www.concretecentre.com/publications](http://www.concretecentre.com/publications)

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The Concrete Centre's vision is to make concrete the material of choice. We provide material, design and construction guidance. Our aim is to enable all those involved in the design, use and performance of concrete to realise the potential of the material.

The Concrete Centre is part of the Mineral Products Association, the trade association for the aggregates, asphalt, cement, concrete, dimension stone, lime, mortar and silica sand industries.  
[www.mineralproducts.org](http://www.mineralproducts.org)

The Concrete Centre provides design guidance, seminars, courses, online resources and industry research to the design community.

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