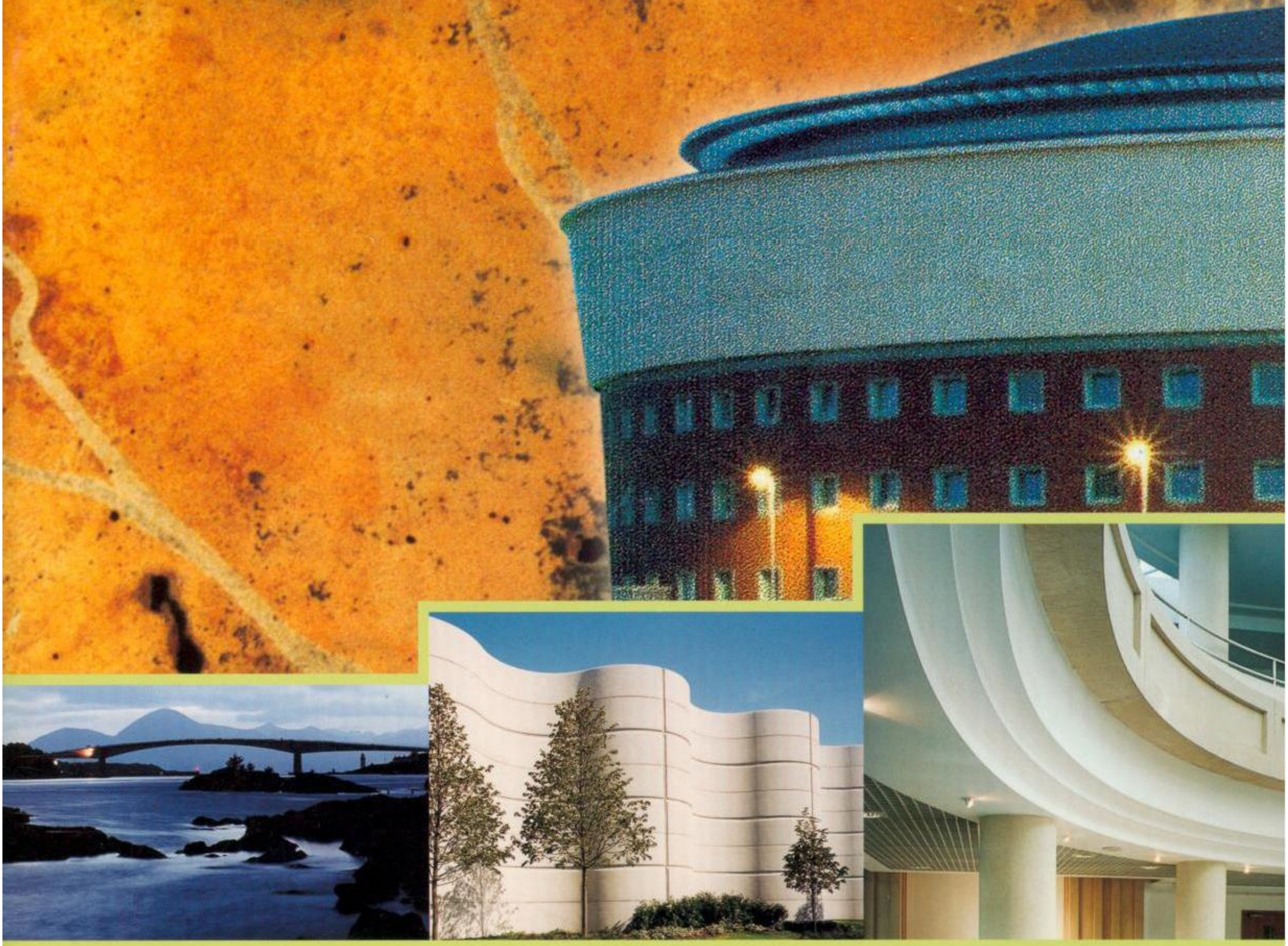
BCA
British Cement Association



Concrete through the ages

from 7000 BC to AD 2000

Foreword

Concrete is the most widely used construction material in the world, and its rise to this position has played a major part in the shaping of civilisation from as long ago as 7000 BC.

This account includes information from an earlier BCA publication, *Highlights in the history of concrete*, and takes the story forward to include the current uses of this remarkable material. It does not claim to be a comprehensive record of the technical development of concrete but rather uses features of its history to chronicle its progress from its earliest known use to the diversity of its present-day applications. While it is acknowledged that many spectacular developments in concrete took place in other countries, this publication concentrates particularly on advances made in the United Kingdom.

A range of examples is used to illustrate the many and varied ways in which concrete forms a major part of our world today - both as inspirational structures that delight the eye, and as the often hidden infrastructure on which we all depend as our world moves into the third millennium.

Thanks are given to all the people, too numerous to mention here, who generously gave of their time, knowledge and experience in highlighting examples of the uses of this durable, economical, versatile, magical material - concrete.

JIM STEVENSON, OBE

Chief Executive, British Cement Association, 1989 to 1999

Acknowledgements

This publication is the result of a joint effort by a group of people, all with a great interest in concrete. Special thanks are given to:

CHRIS STANLEY - the original author of *Highlights in the history of concrete*, who was on the staff of the Cement and Concrete Association (as it was then called) at Fulmer Grange from 1962 to 1987, and is now a consultant working with Can Build Technologies Ltd in Hong Kong.

GILLIAN BOND - an editorial consultant, who updated the historical text with help from a range of specialists and gathered new material for the modern part of the publication.

THE CEMENT MAKERS - Blue Circle Industries, Castle Cement, Rugby Cement and Buxton Lime Industries.

Cover illustrations

The cover features a selection of buildings and structures that have received Concrete Society Awards for excellence. These awards have been made annually since 1968, and over the years almost 400 awards and commendations have been made. The background to the photographs is from a coloured concrete wall panel by artist David Undery.

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British Cement Association
Century House, Telford Avenue
Crowthorne, Berkshire RG45 6YS
Tel: 01344 762676 Fax: 01344 761214
Website: www.bca.org.uk

Concrete through the ages

Concrete from earliest times

Foundation for the future

Concrete is a building material composed of cement, crushed rock or gravel, sand and water, often with chemical admixtures and other materials. It was known to the Romans, the Egyptians and to even earlier Neolithic civilisations. After the collapse of the Roman Empire its secrets were almost lost, only to be rediscovered in more recent times. Indeed, its modern development spans no more than 175 years - 1824 is the date on the patent for the manufacture of the first Portland cement, one of the most important milestones in concrete's history.

There have been remarkable developments in the last few decades of the 20th century, with new structures, new techniques for handling concrete and even new kinds of concrete. Yet, in their way, some of the earlier achievements were no less noteworthy. Since the middle of the 19th century great rivers have been spanned, huge buildings erected, vast sheets of water dammed and large networks of roads constructed. In these and a thousand other ways the face of the world has been changed as a result of the discovery of concrete and the many uses to which it can be put. Concrete has also played a major role in improving the health of the world's inhabitants, through its use for sewage disposal and treatment, and for dams and pipes providing clean water for drinking and washing.

7000 BC – 300 BC

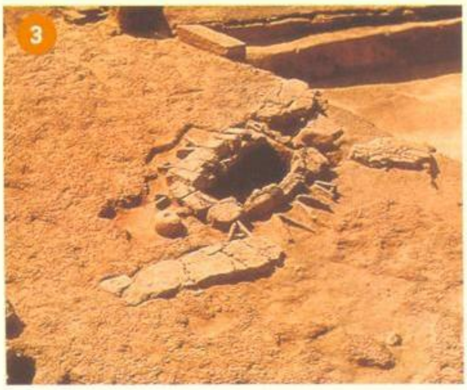
Early beginnings

We may never know who made the first concrete since early attempts probably resulted in a very friable material, all traces of which would have long since vanished. One thing is clear: concrete did not spring to life fully developed, but gradually evolved over many centuries.

The oldest concrete so far discovered dates from around 7000 BC, and was found in 1985 when a bulldozer uncovered a concrete floor during the construction of a road at Yiftah El in southern Galilee, Israel. It consists of lime concrete, made from burning limestone to produce quicklime, which, when mixed with water and stone set to form an early concrete.

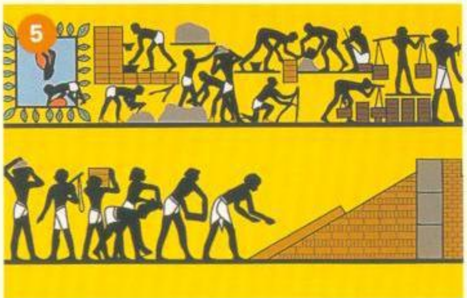
The floor varies in thickness from 30 to 80 mm and was laid on an even base of sandy clay. The concrete has been well compacted and its surface is hard and very smooth. The quantity of lime needed for the 180 m^2 floor would have required an effective lime kiln, and fragments of what was probably a kiln lining have been found at the site.

Another example of ancient concrete dates from about 5600 BC, and came to light during excavations on the banks of the river Danube at Lepenski Vir in the Yugoslav Republic. It was used to make hut floors in part of a village constructed by Stone Age hunter-fishermen, and is reported to be a lime concrete made from a mixture of red lime (brought from almost 200 miles upstream), sand, gravel and water.



From the evidence so far unearthed, it seems that by 5000 BC the art of making concrete may have died out and we have to come down through the years to about 2500 BC to see the re-emergence of any form of concrete. There are conflicting reports, but it would seem that a type of concrete was used between the stone blocks in the Great Pyramid at Giza in Ancient Egypt at about 2500 BC. This has been said by some writers to be a lime concrete, whilst others state that the cementing material was produced from burnt gypsum. One researcher claims that the blocks themselves were actually made from concrete.

The earliest known illustration of concrete work can be seen in a mural from Thebes in Egypt dating from about 1950 BC that shows various stages in the manufacture and use of mortar and concrete. For many years concrete was just used as an infill material for stone walls, and only much later did it develop as a structural material in its own right.



The art of making concrete eventually spread from Egypt around the eastern Mediterranean and by 500 BC was being used in Ancient Greece.

The Greeks used lime-based compositions to cover walls of sun-dried bricks. It is reported that the palaces of Croesus and Attalus were built in this way. It was also used as a render for the porous limestone used for temples, and as a binding material between brick and stone.

Excavations on the island of Rhodes revealed an underground water storage tank near the ruins of the Temple of Athena. This was built of stone lined with a fine concrete to make it water-tight.

1 2 Concrete floor at Yiftah El, southern Galilee, c. 7000 BC

The extent and quality of this concrete floor indicates that late Stone Age man was surprisingly advanced technologically.

The sample shows a curved surface at the junction of the floor with the wall, probably for ease of cleaning.

3 4 Hut floor, Lepenski Vir, Yugoslavia, c. 5600 BC

The trapezium-shaped floor, 250 mm thick, was made from concrete that was laid and then compacted to form the floor. A stone hearth was incorporated into the floor at one end.

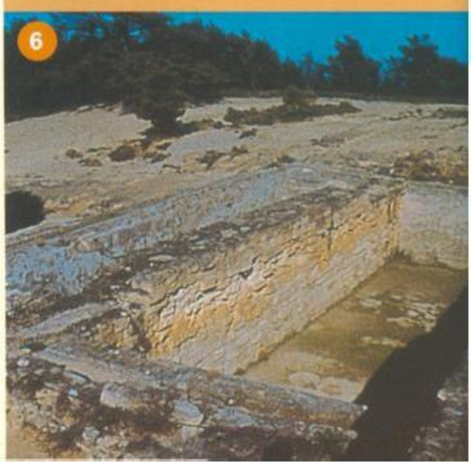
The drawing shows a reconstruction of what this riverside hut is thought to have looked like.

5 Concrete work in ancient Egypt, c. 2000 BC

This is probably the first illustration of the use of concrete and is taken from a mural in Thebes. The top of the picture shows workmen filling earthenware jars with water that is then mixed with lime and used as a mortar for stone masonry. Below a concrete wall faced on both sides with stonework is under construction. Notice the 'site agent', whip on shoulder, keeping a watchful eye on the workers.

6 Water storage tank, Camiros, Rhodes, c. 500 BC

This tank had a capacity of about 600,000 litres, and was used to store water for the city of Camiros until 200 - 300 BC when it was replaced by a new system.



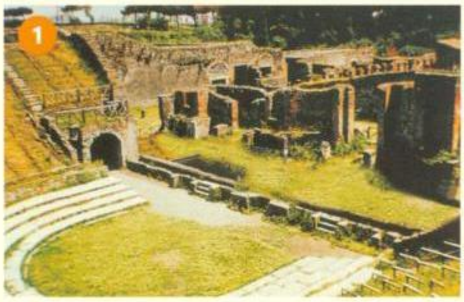
300 BC – AD 150

The Roman achievement

It is possible that the Romans copied and developed the idea of making concrete from the Greeks. Examples of early Roman concrete have been found dating back to 300 BC. The very word concrete comes from the Latin 'concretus', meaning grown together or compounded.

Some time during the second century BC the Romans quarried a pink volcanic ash from near Pozzuoli. Thinking it was sand, they mixed it with lime and found that the mixture resulted in a much stronger concrete than anything they had previously produced.

This discovery was to have a far-reaching effect on building and civil engineering during the next four hundred years, for the material was not sand, but a fine volcanic ash containing silica and alumina which combined chemically with the lime to produce what became known as pozzolanic cement. One of the first large-scale uses of the material was in the theatre at Pompeii, constructed in 75 BC. Measuring some 136 by 104 metres it seated 20,000 spectators.



In 13 BC Vitruvius described in his handbook for Roman architects the preparation of building material by mixing lime and pozzolana to obtain "material that hardened in air and under water". It seems that the rules laid down by Vitruvius for the preparation of concrete were followed throughout the Roman empire.

The Romans apparently attempted to increase the strength of some of their structures by reinforcing them with bronze strips and rods. This was not successful because, although there was some improvement in the tensile strength of the concrete, the bronze had a higher coefficient of thermal expansion than the concrete, and the differential caused spalling and cracking.

Today we use steel reinforcement to improve the tensile and bending strength of concrete, and this is successful partly because steel and concrete have very similar coefficents of expansion and contraction over the range of normal temperatures.

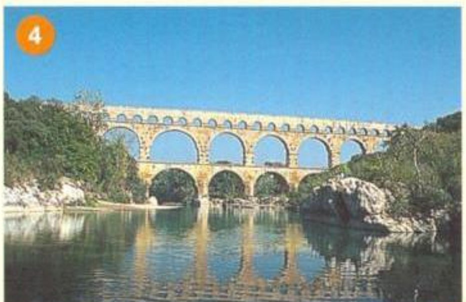
Because of the failure of bronze as reinforcement, the Romans had to design their buildings to carry loads in compression only. An arched form was required to enable the construction of roofs and arches. These required buttresses to provide stability, sometimes resulting in walls of over 8 metres thick.

Lightweigh concrete was developed in order to reduce the need for such massive buttresses and walls. Early attempts to lighten concrete were made by casting earthenware jars into walls and arches. This was followed by the introduction of crushed pumice, which is a very light porous volcanic rock, as an aggregate.

Lightweight concrete was used in some of the arches of the Colosseum, and also in the dome of the Pantheon, which is one of the few Roman buildings to survive intact. With a diameter of over 43 metres, its distinctive domed roof is a testimony to the durability of concrete, and was the largest dome in the world until the 20th Century. It probably inspired Sir Christopher Wren in his design for St Paul's Cathedral in London, the dome of which is only 34 metres in diameter.

The Romans were versatile and enterprising engineers, and used concrete extensively in the foundations of their harbours and bridges. Their aqueducts, reservoirs and sewers were lined with it, and they even made pre-cast concrete blocks for use underwater. At the Italian port of Puteoli, for instance, blocks were left to harden for two months before being sunk into position to form a breakwater.

More than 200 Roman bridges remain, many with striking arches. One of these is the aqueduct at Pont du Gard near Nimes in southern France.

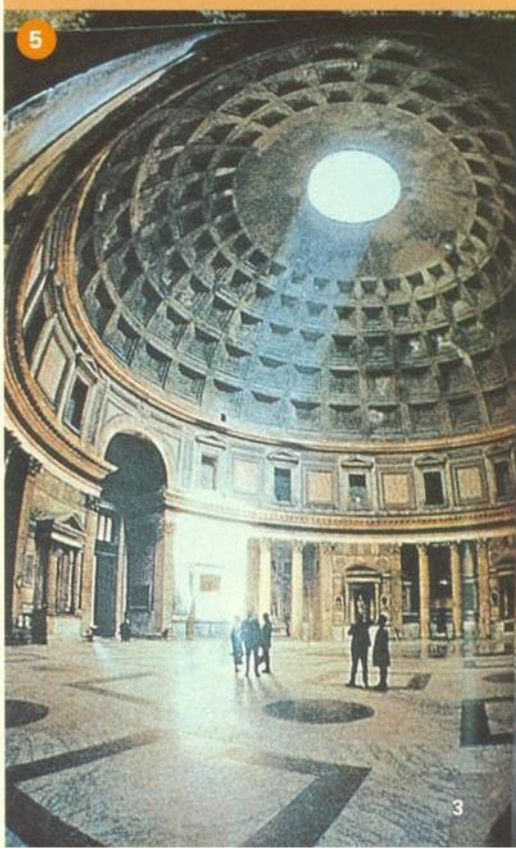


1 Theatre at Pompeii, 75 BC
Notable for the first major use by the Romans of 'pozzolanic' cement, made from a mixture of lime and volcanic ash, and found to be far stronger as a binder than lime alone. The concrete was used as an infill material in walls that had a stone or brick facing.

2 The Colosseum, Rome, AD 82
3 The foundations of the largest and most important amphitheatre in Rome were made of dense concrete, while lightweight concrete was used in some of the arches and vaults. It was faced with stone and decorated with marble. An oval 190 by 130 metres, it seated 50,000 spectators for gladiatorial contests and other shows. It has since been damaged by lightning, earthquakes and, more recently, by vandals.

4 The Pantheon, Rome, AD 127
This was one of the few buildings in Rome to survive intact after the decline of the Roman Empire. The interior view shows the lightweight concrete dome in which crushed pumice was used as an aggregate.

5 Aqueduct, Pont du Gard, Nimes, France, c. AD 150
A fine example of Roman engineering, it stands 48 metres high. The channel along which the water was conveyed is made of concrete, as are the cores of some of the walls. Concrete was also used for the bed of the river.



AD 40 – 500
The Romans fortify Britain

By the first century AD, concrete had come to be accepted as a structural material and, in the period up to the decline of the Roman Empire, a number of outstanding buildings were completed, including the Basilica of Maxentius and the Baths of Caracalla in Rome.

In Britain most of the Roman concrete appears to be a lime concrete, i.e. without the addition of the sand-like material from Pozzuoli. The Romans were cost conscious and tended to make use of the local material wherever possible. In any case, crossing Europe with a cartload of pozzolanic cement, or risking the hazardous sea crossing of the Bay of Biscay was not practical.

In an attempt at making an artificial pozzolanic cement in Britain they incorporated crushed bricks, tiles or pottery (which provided the silica and alumina - see page 34) into the mix, but lime concrete was suitable for most purposes and had a strength in some cases of over 14 newtons/mm^2. (For comparison, the strength of most modern structural concrete lies between 30 and 60 N/mm^2.)

In AD 46, in the reign of the Emperor Claudius, two phari, or lighthouses, were built on the cliffs at Dover to guide the Roman fleet to the port. The eastern one, near where Dover Castle was later built, is octagonal in shape. The four storeys remaining are 13 metres high, and at one time were surmounted by a Medieval top storey. They were built of rubble bonded with lime mortar, and originally faced with green sandstone, which has since been lost.

In AD 122, the Roman Emperor of the time, Hadrian, visited Britain, the northernmost corner of his far-flung Empire. The object of this visit was the re-organisation of the frontier's defence system. The result was Hadrian's Wall, one of the largest Roman construction projects. In places over four metres high, it stretches some 75 miles from the Solway Firth to the Tyne.

Another example of defensive construction is Portchester Castle in Hampshire. This large square fort, enclosing nine acres, is one of the most notable remains of Roman Britain. It dates from the end of the third century AD, and was one of a series of forts constructed to defend the south-east coast of Britain against continuing waves of Saxon invaders. Concrete was used for the foundations and the core of the walls, which were faced with large flints embedded in lime mortar.

In those days, concrete was made by pouring the mortar over a layer of broken rock or stone. This was then left to harden before the process was repeated with another layer. The stone was broken up to be of uniform size, with the harder stones often used in the foundations and the softer and lighter stones in the roofs.

The Romans also used concrete widely for the construction of villas and farms in Britain. The concrete was used in walls and for floors, some of which were overlaid with an elaborate decoration of mosaics.

Over a period of 800 years the Romans developed concrete from a crude filling material to being one of the main structural materials, but with the decline of the Roman Empire most of the knowledge gained in the use of concrete seems to have disappeared almost completely during the Dark Ages.

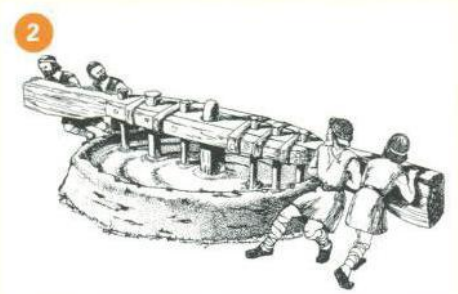
1 Pharos lighthouse, Dover, AD 46
Pictured here with Dover Castle in the background, this lighthouse would have been visible from the French coast. The remaining concrete core is seen alongside the Medieval church, for which it served as the belfry.

2 Hadrian's Wall, Northumberland, AD 122 - 130
One of the largest Roman construction projects, it stretches for some 75 miles, its core bonded together with concrete of enduring strength. Apart from the wall, the defensive system included a series of 16 forts, each housing 500 to 800 men, 80 small forts, known as milecastles, and 158 towers.

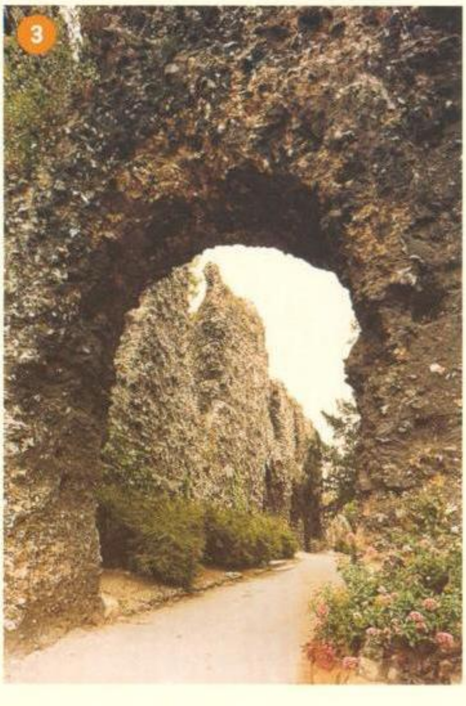
3 Portchester Castle, Hampshire, c. AD 250 - 300
Fort built by the Romans in the third century AD as part of their defences against the Saxon invaders. *(The buildings within the square perimeter wall and the tower in the corner were constructed much later.)*

The Middle Ages and beyond

It was thought that the Normans re-introduced the art of concrete-making into Britain, but excavations in Northampton brought to light the remains of three Saxon concrete mixers dating from about 700 AD. The largest mixer had a diameter of three metres and the other two were two metres. They took the form of shallow bowls cut into the bedrock, with a central post hole, and the smaller mixers were lined with wattle and daub. Analyses of concrete and mortar deposits taken from the mixers show that a local limestone was used as aggregate and burnt lime as the binding agent.



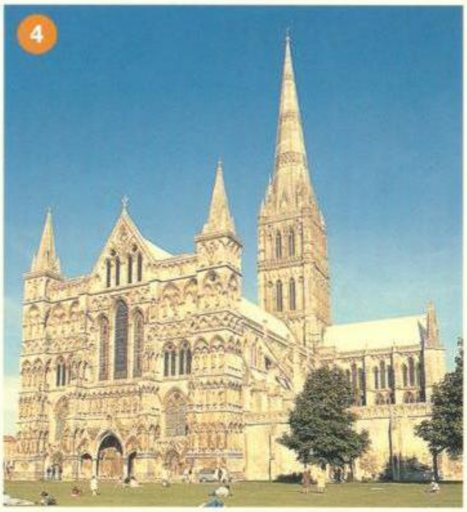
Saxon concrete work appears to have been limited, and it was the Normans who brought concrete-making back to Britain. The Norman concrete work was not unlike that of the early Roman period: concrete was used as infill material in walls that were faced with stonework.



The Normans used sand and lime mortar in their buildings, and found that the addition of pounded tiles and bricks improved hardness and durability by producing a similar reaction to that of the Roman pozzolana.

An interesting example of Norman work can be seen at the remains of Reading Abbey in Berkshire, where the stone facing has been almost completely removed leaving what is, in effect, a concrete skeleton.

Concrete was widely used in castles, including the White Tower in the Tower of London, and in Dover, Corfe and Rochester Castles. In churches and cathedrals, concrete was used principally for foundation work. Salisbury Cathedral, which has the tallest spire in Britain, has concrete foundations that lasted for over 700 years before some recent strengthening was required.



Little Moreton Hall, a magnificent half-timbered house in Cheshire, includes a wing built around 1580 that has first and second floors made from lime-ash, a mixture of lime, sand, wood ash and gypsum. This material was used in rooms containing fireplaces in order to eliminate the hazard inherent in the traditional timber floor, and the practice was quite common in the East Midlands where gypsum is to be found.

Apart from foundations and the occasional floor, very little concrete was used in the Medieval and Renaissance periods, although some reference to it was made in 1568 by the French architect Philbert de l'Orme.

1 2 Saxon concrete mixer, Northampton, c 700

One of three mixers unearthed during redevelopment work in Northampton. The concrete was apparently mixed by paddles fixed to a beam that rotated round a central axis; notice the curved grooves left by the paddles. The drawing shows an artist's reconstruction of the mixer in action.

3 Reading Abbey, Berkshire, c. 1130

The original stone facing to this wall has fallen away or been removed for use in other buildings, leaving the concrete core standing on its own.

4 Salisbury Cathedral, Wiltshire, 1220 - 1265

The tallest spire in Britain was added a century later, and stood for some 600 years on its original concrete foundations before some strengthening was required.

5 Little Moreton Hall, Cheshire, c. 1580

A notable feature of this famous Elizabethan manor house is the lime-ash flooring in one wing. This has recently been restored in the original materials.

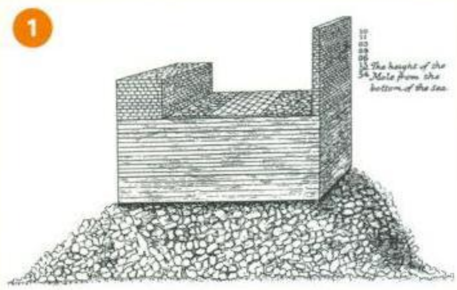
1670 – 1824

Experiments with new cements

There was very little use of concrete by the British until the 18th century, with the notable exception in the 1670s of the construction of a breakwater or mole at Tangier, a British outpost on the North African coast. There, Henry Shere, a young engineer, supervised the mole's construction, based on one at Genoa.

The mole was made from a series of wooden chests, which were sunk in place and then filled with concrete consisting of stones together with mortar made from lime and Italian trass (a natural pozzolana). Shere experimented with some 30 different mixes to select the one that set the hardest under water, and it was on this property that the success of the project relied.

By 1683 he had completed a mole some 440 metres long, in what must have been the largest civil engineering structure made by British engineers until the 19th century. At this stage a political decision was made to abandon the outpost, and the mole was demolished - an engineering triumph that was destroyed before it could prove itself.



A revival of interest in concrete came in the middle of the 18th century and in 1753 George Semple used it in the foundations of the Essex Bridge in Dublin.

In 1756 a Leeds engineer, John Smeaton, was commissioned to build the third lighthouse on the Eddystone Rocks in the English Channel 14 miles south-west of Plymouth. The two previous lighthouses had been constructed of timber; one had burnt down and the other had blown away in a gale.

Smeaton soon realized that the only practical method was to build with blocks of stone, but this presented the problem of how to bind them together to form a rigid monolithic structure. The cements generally available in 1756 were weak and slow setting, and as the blocks would be constantly soaked by the sea, the mortar would be washed away before it could harden.

Smeaton began testing mortars from different parts of the country. He found that lime mortar would set under water if the limestone used in its manufacture contained clay (which provided the silica and alumina). But lime mortar did not itself solve the problem and he eventually settled on a mixture of burnt limestone from South Wales and an Italian trass. Smeaton's experiments were the first scientific investigations and paved the way to modern cements.

The lighthouse, whose stone blocks were keyed and cemented together, took three years to build, and came into operation in 1759. When part of the structure began to weaken in 1876, it was replaced by the present lighthouse, which is far larger than its predecessor. At the request of the people of Plymouth, Smeaton's Tower was dismantled as far as its base and re-erected as a monument on Plymouth Hoe, where it stands to this day. The undismantled stump still exists as defiant as ever on the rock on which Smeaton built it some 240 years ago.

Smeaton outlined his researches into cement in a book entitled *A narrative of the Eddystone Lighthouse*, a copy of which was purchased by chance in 1813 by a young Leeds bricklayer, Joseph Aspdin. The book must have had a profound effect on Aspdin and probably resulted in his starting research on cement.

Towards the end of the 18th century there was revival of interest in developing new types of cement, with many formulations which, in essence, were little better than Smeaton's attempts. Perhaps the best known was a cement discovered by accident by a vicar, the Rev. James Parker of Northfleet in Kent, who threw a pebble collected from the beach onto his fire, where it was thoroughly calcined. After some experiments he developed a cement which he patented in 1796 under the name 'Roman' cement because, it is suggested, he believed he had discovered how to make the cement of ancient times.

The pebbles, which were nodules of septaria or cement stone from the London clay, contained lime, silica and alumina, and were burnt in a kiln before being crushed to produce the Roman cement. Large quantities were collected from the beaches in the Thames Estuary and other places to make a cement that remained popular until the middle of the 19th century.

1 The breakwater at Tangier, 1670 - 1680

Built to provide protection against the Atlantic Ocean and Barbary pirates, this mole was constructed of a series of wooden chests filled with stones and mortar that set under water.

2 Eddystone Lighthouse, 1756 - 1759

A print showing Smeaton's lighthouse on the Eddystone Rocks. The foundations, for which Smeaton developed his cement that set under water, still stand alongside the present lighthouse on the Eddystone reef.

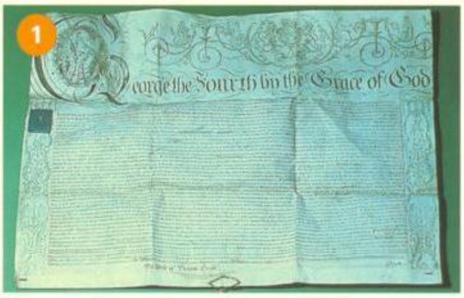
3 Smeaton's Tower, Plymouth

This lighthouse stood for 117 years on the Eddystone Rocks before being re-erected on Plymouth Hoe at the request of the townspeople.

1824

The invention of Portland cement

A great milestone in the history of concrete was the invention of Portland cement by Joseph Aspdin. Following his researches in Wakefield he took out a patent on 21 October 1824 for the manufacture of the world's first Portland cement, which he claimed to have been making since 1811. He chose this name because, when set, he thought it resembled Portland stone in colour and not, as people often think, because it was made in Portland.



At around this time, cement making was becoming well established in north Kent along the banks of the Thames and Medway rivers. This was due to the high quality and abundance of the raw materials, chalk and clay. In addition to the Roman cement made by James Parker of Northfleet, there was an artificial Roman cement made by James Frost who established a works in Swanscombe in 1825, producing 'British cement'. These and other cement-making works were the start of a major Kentish industry that eventually evolved to form the present day company, Blue Circle.

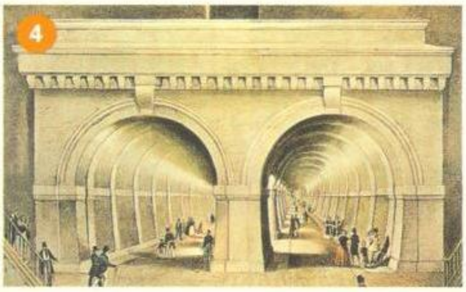
Aspdin's was undoubtedly the most superior cement of its day, but since that time considerable improvements have been made in the cement-making process, so that today's Portland cement resembles that produced by Aspdin in name and basic ingredients only.

At this time, Joseph Aspdin possibly didn't envisage the many potential uses for Portland cement. It is likely that he saw his cement more as an external grade of plaster to be used to render brickwork, thus producing relatively cheaply the appearance of Portland stone blocks.

He established his first cement works around 1828 at Kirkgate in Wakefield. These were demolished in 1838 and by 1843 he had set up a new works at Inge Road in Wakefield.

So far as can be ascertained, only one building incorporating Aspdin's cement still survives. It is the Wakefield Arms, a brick-built structure near Kirkgate Station, faced on the outside with a rendering of Portland cement and sand; it is very close to the site of the cement works.

Aspdin's younger son, William, left home about this time to seek his fortune 200 miles to the south in London. He set up a cement works at Rotherhithe, to the east of London, at a time when Isambard Kingdom Brunel was having problems constructing the Thames Tunnel.



In his booklet, published several years later, William claims that Brunel carefully placed several tons of his cement into the river when the tunnel roof collapsed. This sealed the break and Brunel was able to pump the brick-built tunnel dry and then reline parts of it with mortar made with Portland cement. Despite the problems with its construction, this was the world's first significant underwater tunnel.

In 1847, William Aspdin moved to Northfleet, where he set up another cement works. One of the cement kilns from this still survives at the site of the present day Blue Circle works. Then in 1852 Aspdin moved to Gateshead, and set up what was probably the largest cement works in the world at that time. In 1860 he started cement manufacture in Germany, where he died four years later.

The cement-making process was improved by Isaac Johnson who managed a cement works in Swanscombe and later, in 1856, took over Aspdin's abandoned works in Gateshead. He raised the temperature at which the cement was fired, and is regarded by many as the father of modern Portland cement.

1 Portland cement patent, 1824
Joseph Aspdin's original patent for the manufacture of Portland cement. The cement was so named because its colour resembled that of Portland stone.

2 Joseph Aspdin's first cement works at Wakefield, c. 1828
From a painting commissioned by the Aspdin family, this shows the bottle kilns where batches of the raw materials were burnt to produce cement.

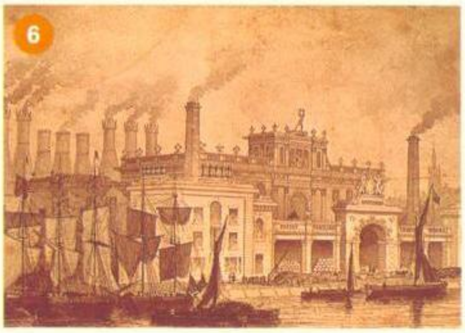
3 The Wakefield Arms, Kirkgate, Wakefield, 1843 -1845
The only known surviving building in which Joseph Aspdin's original Portland cement was used. It is a brick-built structure, rendered on the outside with Portland cement to resemble stone.

4 Thames Tunnel, Rotherhithe, London, 1825 - 45
After a series of mishaps, Brunel's tunnel was eventually built and is still in use today carrying underground trains on the East London line between Rotherhithe and Wapping. It has been restored recently in the original style.

5 Cement kiln, Northfleet, Kent, 1848 - 1850
The oldest surviving Portland cement kiln, from part of William Aspdin's Northfleet works.

6 Aspdin's Portland Cement Works at Gateshead-on-Tyne, 1852
One of the largest cement works in the world at that time. The barrels of cement can be seen stacked for shipping. The royal coat of arms above the gate is nearly 7 metres high, and the works are crowned by a colossal concrete figure of Hercules vainly endeavouring to break upon an anvil a beam of bricks joined together with Portland cement.

Portland cement fairly quickly replaced Roman cement in mortars and renders but, with a few exceptions, was not generally mixed with aggregates to make concrete for use in buildings until the mid 1800s.



The mid 1800s

Concrete in housing

The very first all-concrete house was built for John Bazley White, a major manufacturer of Roman cement, at Swanscombe, Kent, in 1835. It had concrete walls, tiles, window frames and decorative work - and even concrete gnomes in the garden! The only thing it lacked was a first floor of concrete; this would have required a knowledge of reinforcement that did not come until some years later.

Between 1845 and 1848 a considerable quantity of concrete was used in the construction of Queen Victoria's country mansion, Osborne House, on the Isle of Wight, which was designed and built by Thomas Cubitt under the supervision of the Prince Consort.

William Aspdin tried to promote the early uses of concrete for house construction, and started work in 1850 on a vast concrete mansion called Portland Hall, overlooking Gravesend in Kent. It was abandoned when only half completed after it had cost almost £40,000. Only part of the house survived, together with a small section of the boundary wall, which is capped by what are thought to be some of the earliest commercially produced precast concrete units.

At this time cement was sold by the barrel, and a ship loaded with William Aspdin's cement was sailing down the River Thames when it ran aground on the Isle of Sheppey. The local people quickly removed the barrels from the wreck, thinking they contained whiskey, only to find that they were full of cement, which had already set. They held a meeting and decided, so the story goes, to take the barrels to the beach and use them to build a public house.

A more conventional use was made of cement in 1870 when a crescent of 14 concrete houses was built on the seafront in Folkestone, Kent. They were designed and constructed by John Pope and Son, a local firm of architects and builders. They used iron formwork that was raised as concreting progressed - a technique that developed into slipforming and is still in use today. The exterior was rendered in Portland cement and sand.

In about 1875, the leading cement manufacturer of the time, Isaac Johnston, built a handsome three-storey house in Gravesend to demonstrate the use of his cement.

In Wales, a number of concrete houses, a farm, a school and a bridge were built as part of the Gregynog Estate near Newtown in Powys between about 1870 and 1894 by the Hon. Henry Hanbury-Tracy. It must have been a daring experiment as the structural use of concrete was unknown in the area at the time. The houses were built entirely of in-situ concrete with walls 0.3 metre thick. The floors and roofs were made of concrete, the latter covered with slates. Even the staircases and chimneys were of concrete.

1 First all-concrete house, Swanscombe, Kent, 1835

Practically everything is built of concrete; there was even a concrete gnome in the front garden.

2 Osborne House, Isle of Wight, 1845 - 48

Queen Victoria's country mansion. A considerable amount of concrete was used in its construction and for rendering the walls.

3 Portland Hall, Gravesend, Kent, 1850

Originally built by William Aspdin to demonstrate the uses of Portland cement, the surviving part was renamed West Hill House. and was demolished in the 1970s Two of the precast units from the wall are shown as a cut-out.

4 The Ship on Shore, Sheerness, Kent, 1848

The original pub is now called The Grott and is used for meetings. The picture shows the wall made from the cement that had set into the shape of the barrels.

5 Marine Crescent, Folkestone, Kent, 1870

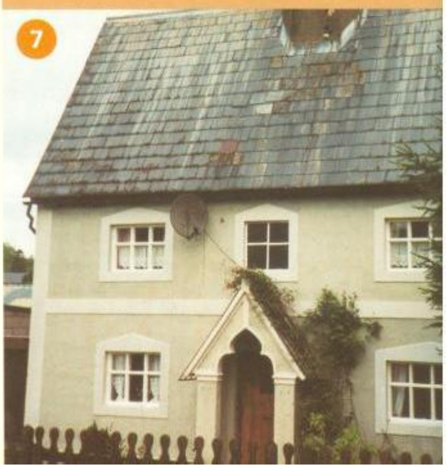
This attractive crescent of 14 houses was built on the sea front at Folkestone. They are pictured here in the 1970s while in use as hotels.

6 Johnson's House, Gravesend, Kent, c. 1875

Isaac Johnson superseded the Aspdins as the leading manufacturer of Portland cement. This house was built of concrete to demonstrate the use of his cement.

7 1, Concrete Cottages, Tregynon, near Newtown, Powys, Wales, c. 1880

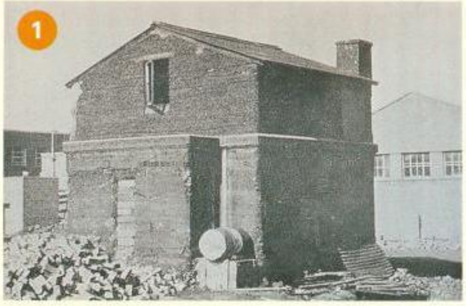
Still called by their original name, these cottages were built entirely of concrete except for the roof slates. The window over the Gothic porch has always been painted onto the wall as part of the desig



1854

The advent of reinforced concrete

As early as 1830 the idea of reinforced concrete was first mentioned in the *Encyclopaedia of cottage, farm and village architecture* which suggested that a lattice of iron tie rods could be embedded in concrete to form a roof. In 1848 the world's first reinforced concrete boat was built in France by Jean-Louis Lambot. He plastered a layer of fine concrete or mortar over a network of iron rods and mesh to produce what is now known as ferro-cement. It created quite a sensation when shown at the Paris Exhibition of 1855.



The man generally credited with the invention of reinforced concrete is a little-known Newcastle builder, William Wilkinson. In 1854 he took out a patent for embedding a network of flat iron bars or wire rope in floors and beams of flat or arched concrete. This appears to be the first use of reinforced concrete as a composite structure as opposed to the French idea of metalwork encased in concrete. Wilkinson has thus come to be regarded as the first person to understand the basic structural principles of reinforced concrete.

One of the earliest uses of reinforced concrete was in a pair of cottages built in 1866 by Joseph Tall at Bexleyheath in Kent. A lattice of hoop iron was embedded in the original flat roofs and he used his patent method of formwork for casting the monolithic concrete walls.

By the late 1860s concrete was being widely used for a variety of applications in England but little attention was given to Wilkinson's ideas and most concrete was unreinforced.

An example of mass unreinforced concrete is the Waverley Castle Hotel at Melrose in Scotland that was constructed in 1869 as a hydropathic spa. In its day it must have qualified as one of the world's largest concrete structures. The concrete is in good condition and the hotel is still in use.

In 1870, one of the first concrete bridges was completed at Homersfield near Bungay in Suffolk. The Flixton Bridge has a single span of 16.5 metres and consists of a cast iron frame completely embedded in concrete. It was in regular use for 100 years but unfortunately was not wide enough to cope with the increasing volume of traffic, and another bridge was built in 1970. The original bridge was restored and brought back into pedestrian use in 1996.

The fire-resisting quality of concrete was soon realised and became a major selling point, particularly for industrial buildings. At first it was used chiefly for reinforced concrete floors, especially in cotton and woollen mills where, in the squalid working conditions that prevailed, the incidence of fire was very high.

A wine and spirit store erected in Bridge Street, Reading, in about 1870 was another very large concrete structure. Built of mass concrete, it had four storeys. The walls were of solid concrete as were the floors, which were vaulted and supported on cast iron columns, each calculated to carry a load of 100 tonnes. After more than 100 years of service, the store was demolished to make room for new developments.

1 Wilkinson's reinforced concrete house, Newcastle, c. 1860

This was the first use of reinforced concrete in a building. Wire ropes were used to provide the reinforcement in the ceiling. When the house was demolished in 1954, these ropes were found to be still in good condition.

2 Joseph Tall's concrete cottages, Bexleyheath, Kent, 1866

These cottages had walls cast in situ using a patent formwork system. These are amongst the earliest surviving reinforced concrete houses in the world. The original flat roofs were replaced with the pitched roofs shown in the photo.

3 Waverley Hydropathic Hotel, Melrose, Scotland, 1869

Pictured here at the turn of the century, this hotel must have been one of the world's largest mass concrete structures at the time it was built.

4 Flixton Bridge, Homersfield, Suffolk, 1870

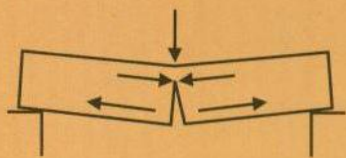
Britain's oldest surviving concrete bridge. The 16.5 metre span has a cast iron frame completely embedded in concrete. It is shown here after restoration in 1996.

5 Wine store, Reading, Berkshire, c. 1870

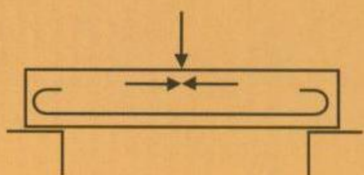
This interior photograph shows one of the solid vaulted concrete floors supported on cast iron columns.

6 The principles behind reinforced concrete

Concrete is strong in compression, but relatively weak in tension.



When an unreinforced beam is loaded at mid-span, the top compresses and the bottom of the beam is in tension.



Adding reinforcement overcomes this weakness in tension and controls cracking.

1870 – 1890

Stately homes and towers

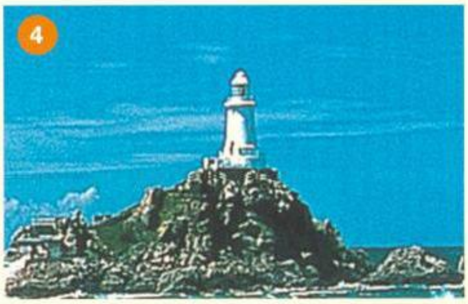
During this period some stately homes were built from concrete. One of these is Down Hall, near Hatfield Heath in Essex, which was completed in 1873. It was described as a striking example of the best concrete work of the period. The contractor, Francis Drake, used his patent formwork system, which was developed from that of Joseph Tall.

Meanwhile, in Scotland, a wealthy English industrialist, Octavius Smith, created virtually an entire estate in concrete. Ardtornish Tower, built of mass concrete with sandstone cladding, is its centrepiece.

Precast concrete had been in use since the 1840s as a substitute for stone. It was used for paving, garden ornaments, balustrading, sills and finials. An interesting advance came in 1875 when William Lascelles patented a precast concrete low-rise housing system. R Norman Shaw, an eminent architect of the time, produced a number of designs suitable for this method of construction. Lascelles lived in Croydon and built a number of concrete houses in the town.

The houses consisted of a wooden frame to which panels, measuring about 1 by 0.75 metre and up to 40 mm thick, were fixed. The panels were usually made from crushed coke or cinders mixed with Portland cement. The mould was suitably prepared to produce an ornamental finish and in some cases iron oxide was added to provide a red colour. The red has since weathered to a pleasant terracotta shade but at the time the bright red colour attracted much attention and led to derisory remarks in the architectural press.

The drawing room ceilings were constructed from precast slabs carried on beams, with an attractive pattern of flowers and ripening fruit in a style often reproduced in moulded plaster in large stately homes.



The first lighthouse to be constructed entirely from concrete was at La Corbière in Jersey. Built in 1873, it still stands on a very dangerous rocky outcrop to the south west of the island.

On a more whimsical note, the village of Sway on the southern edge of the New Forest is dominated by one of the most curious concrete structures ever built in this country. It is a folly in the form of a tower 66 metres high which, at the time, was the tallest concrete structure in the world. The builder was Andrew Peterson, a retired Judge in the High Court of Calcutta who completed the tower in 1885.

There are 11 rooms within the tower, which is surmounted by an octagonal observatory. The staircase is situated within an adjacent tower and comprises 330 precast concrete steps; the cornices and window mouldings are also precast.

In 1883 the New Jerusalem Church near Crystal Palace became the first concrete church to be built in London. It was built in mass concrete with walls 0.75 metre thick to which a red pigment was added. Portland cement was used and the aggregate was dug on the site. The building was designed and built at a cost of £3,000.

1 Down Hall, Hatfield Heath, Essex, 1873

A rare example of a stately home in concrete, with fine decorative panels set into the walls. The building is noted for the extremely fine way in which the surface has weathered and enhanced its appearance.

2 Ardtornish Tower, Argyllshire, Scotland, 1885 - 91

The centrepiece of an estate built entirely of concrete, this is a wonderful building in a beautiful setting on the Morven peninsular.

3 Precast concrete house, Croydon London, 1882.

Concrete panels were fixed to a wooden frame; the system was developed and patented for low-cost, low-rise housing by William Lascelles. The ceiling in the front room of the house displays precast concrete panels decorated in a style similar to the plaster mouldings in large stately homes.

4 La Corbière Lighthouse, Jersey, 1873

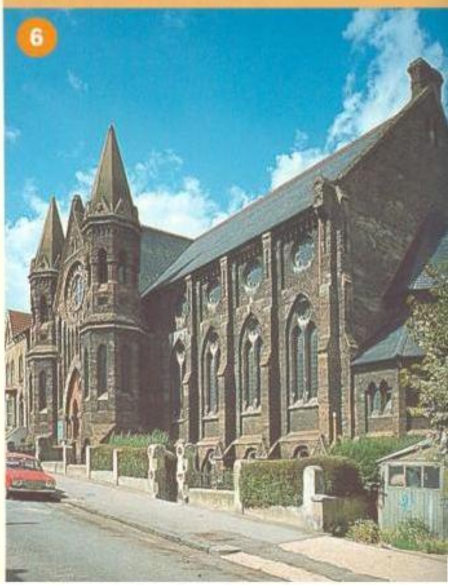
Built by Scottish engineer, Imrie Bell, the lighthouse and platform are about 13 metres high.

5 Sway Tower, New Forest, Hampshire, 1885

This 'folly' was built largely to relieve unemployment by an eccentric but benevolent landowner. At the time it was the tallest concrete structure in the world.

6 New Jerusalem Church, Crystal Palace, London, 1883

Weatherbeaten but still impressive, this church was built entirely in unreinforced concrete. It is still there today, having been converted into flats in the late 1980s.



1890 – 1920

The growth of structural concrete

By the 1890s concrete was being used extensively for docks, river banks and bridges. In 1897 one of the longest bridges at the time was constructed as part of the extension of the railway line from Fort William to Mallaig in the Western Highlands of Scotland. The bridge, known as the Glenfinnan Viaduct, is over 300 metres in length and has 21 spans, some of them almost 31 metres above ground level. It was constructed entirely from mass concrete by Robert McAlpine, who was known as 'Concrete Bob' because of his enthusiasm for the material.

But what had happened all this time to reinforced concrete? Wilkinson's ideas had not attracted much attention and it was left to the French to pioneer its development. A number of famous names were involved but it was perhaps one man, François Hennebique, who had the greatest impact on the development of reinforced concrete in the United Kingdom.

In 1897 the directors of Messrs Weaver and Co. decided to expand their business by constructing a second flourmill in Swansea, and spoke to Hennebique's agent, L G Mouchel, who had just moved to the town.

After completing several hundred projects in Europe, this was Hennebique's big opportunity to gain a foothold in Britain. By August 1898 a new chapter in the history of concrete in this country had been opened; Weaver's Mill was the first multi-storey reinforced concrete framed building to be erected in the UK.

The first reinforced concrete bridge in Britain was constructed on the Hennebique system at Chewton Glen in the New Forest and completed in 1901. There are at least six bridges in England with a plaque, all claiming to be the first reinforced concrete bridge but dating from 1903 to 1921! For the next decade this system was used for 80% of reinforced concrete bridges.

The popularity of the Mouchel/Hennebique system was so immense that its use dominated structural concrete until 1920, being used for everything from industrial buildings to bridges, wharves, reservoirs and even boats. As construction methods were perfected, so speed of erection increased. It scored many more 'firsts', including the first reinforced concrete water tower, of 68,180 litres capacity, built in Bournemouth's Meyrick Park in 1900.

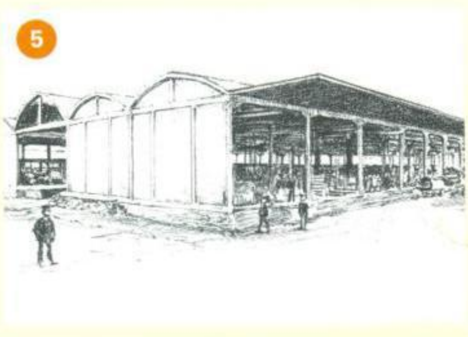
But there were many other reinforcing systems in use at the time - this was the golden age of the entrepreneur that culminated in 1907 with the publication by the Royal Institute of British Architects of the first national code of practice for reinforced concrete.

In 1908 work began on the reinforced concrete frame of the Royal Liver Building, Britain's first sky-scraper. The 15 floors were completed in just over a year. Crowned by the Liver Bird at almost 100 metres high, it was the tallest concrete building in the world at the time.

The first reinforced concrete factory in Britain was the Uniroyal Rubber Factory, erected in 1912 in Dumfries. It was in continuous use for 77 years, at which stage it underwent repairs which should extend its life for another 25 years.

But the use of the Hennebique system was not restricted to industrial buildings and structures. In 1912 Tillycorthie Mansion was completed in rural Aberdeenshire. It was probably the last designed in the Scottish Baronial style and in the 1980s was converted to flats.

All the while, developments in cement manufacture were taking place, and in 1904, the first British Standard for Portland cement was published.



1 Glenfinnan Viaduct, Scotland, 1897
Still an essential part of the rail link to the Western Isles, this unreinforced concrete viaduct is carrying trains far heavier than any envisaged at the time of its construction. The photograph shows one of the tourist steam trains that run in the summer.

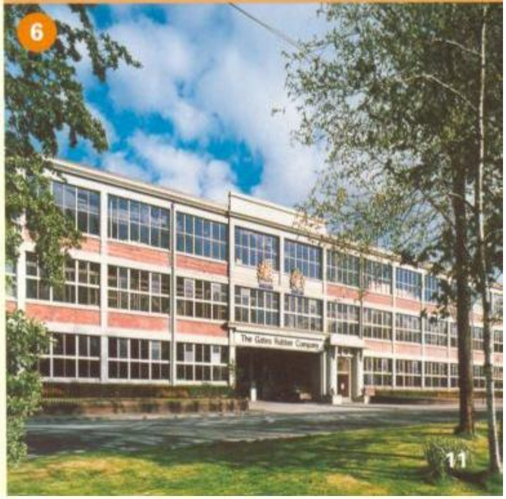
2 Weaver's Mill, Swansea, South Wales, 1898
Generally regarded as still in good condition at the time of its demolition in 1984, this was the oldest surviving reinforced concrete structure in the UK. Note the overhanging cantilever above the loading bay - this would have been impossible to achieve without reinforcement.

3 Water tower, Meyrick Park, Bournemouth, 1900
This was the first reinforced concrete water tower to be constructed in Britain.

4 Royal Liver Building, Liverpool, 1909
This Merseyside landmark is notable for being the first concrete-framed British skyscraper. The building was clad with stone around the reinforced concrete frame; nowadays the cladding, too, would almost certainly be of concrete.

5 La Gare de Bercy, Paris, 1910
The first concrete shell roof - here was the realisation that concrete could be moulded in such a way that its strength would be derived from its shape.

6 Former Uniroyal Rubber Factory, Dumfries, Scotland, 1912
Pictured here in 1989, this factory is still performing well after some repair work to extend its life for 25 years.



1920 – 1945

Concrete comes of age

Between the First and Second World Wars attention focused on the development of prestressed concrete. It is hard to realise that 70 years ago prestressing was little more than a theory and an object of research for a handful of hopeful engineers who had a vision of its enormous potential. Today this potential is fully realised and hardly a major building programme is undertaken in the world without prestressing being taken into consideration as a possible solution.

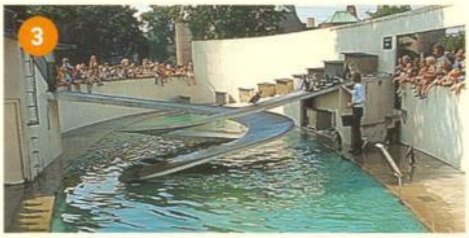
Prestressing is a form of 'load balancing' in which compressive stresses are introduced into those parts of a concrete structure that will later be subjected to tensile stresses due to applied loads. The prestress is applied by tensioning high-tensile steel. It permits longer spans compared with reinforced concrete, and leads to slender and graceful designs.

The French engineer, Eugene Freyssinet, is generally regarded as the father of prestressed concrete; he had started developing ideas as a bridge designer as early as 1908. His research revealed that success depended on the use of both high quality concrete and particularly of high-tensile steel in order to minimise prestressing losses. By 1928 work in Britain had confirmed Freyssinet's work on concrete and helped him to refine his theory of prestressing. Freyssinet then devoted himself full time to prestressed concrete and so began its emergence as a practical technique on the Continent.

The first practical application of prestressing in Britain was in 1940 when the Ministry of War Transport stockpiled prestressed bridge beams for use in an emergency. It was not until well after the Second World War that prestressing was used to any great extent in Britain.

Between the World Wars, the use of reinforced concrete continued to expand. Wembley Stadium was built in 1923 in time for the FA Cup Final, when it is reputed to have held a crowd of 200,000. It is claimed to be the largest monumental building ever to have been constructed in reinforced concrete. At the time of writing it is not yet clear whether the famous twin towers will survive the extensive updating programme that is required to bring the stadium into the third millennium.

Reinforced concrete's ability to take unusual shapes was vividly illustrated by the Penguin Pool at London Zoo. Built in 1935, this was one of the structures that opened up new aesthetic as well as structural possibilities for concrete.



A building with a more familiar purpose is the De La Warr Pavilion in Bexhill-on-Sea. This is an example of a style of architecture directly derived from the nature of reinforced concrete construction.

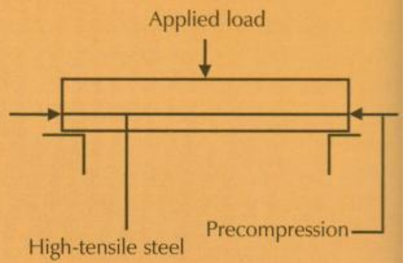
The desire to experiment with reinforced concrete was the motivation for a group of young architects who formed the Modern Movement in Britain in the 1930s. Much of their work took the form of private houses with characteristic flat roofs, white walls and wide windows.

Another landmark building during this period is the block of flats known as Highpoint 1, constructed in north London in 1935. Here the walls and the frame were of in-situ reinforced concrete, used in a new and effective way to provide an elegant ambience typical of the 1930s.

It was in 1931 that the first ready-mixed concrete was produced at a plant west of London, and so began the bulk production of a more consistent and readily available material.

By the end of the 1939 - 45 war, concrete was the material in which mainstream architecture in Europe was constructed and Britain was set to follow.

1 How prestressing works
Concrete is strong in compression, but relatively weak under tension. Tensioned steel puts the concrete into a state of compression before the load is applied.



2 Wembley Stadium, London, 192
The twin white towers that became synonymous with football in Britain were built of reinforced concrete.

3 The Penguin Pool, London Zoo, 1935
The twin spirals of reinforced concrete ar still a source of delight to visitors and penguins alike.

4 The De La Warr Pavilion at Bexhill-on-Sea, Sussex, 1936
Its vigorous curves and dramatic contrast between wall and window provided an example of form derived from the nature of its construction.

5 The White House, Grayswood, Surrey, 1932
One of the earliest Modernist houses in the country, this Grade 11 listed building arranged in a fan shape around a central staircase, and has a roof terrace with built-in flower boxes.

6 Bridge over the Salgina Gorge at Schiers, Switzerland, 1930
One of the later examples of the elegant reinforced concrete work of the Swiss engineer, Robert Maillart. From 1905 his beautiful curved bridges had demonstrate the aesthetic possibilities of concrete.

7 Highpoint 1, Highgate, London, 1935
A landmark of the 1930s, this building sti appears fresh and attractive today.

1914 – 18 and 1939 – 45

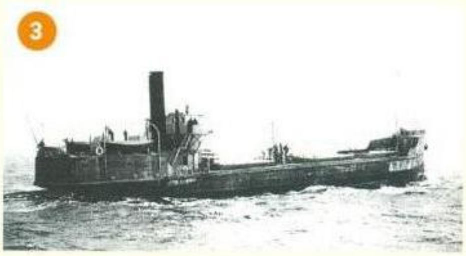
Concrete and war

During the First World War an incredible plan was conceived to cope with the new German threat posed by the increasing use of submarine warfare. The intention was to build up to 16 concrete towers to be positioned at intervals across the English Channel. From these, controlled mines were to be operated, thus preventing the submarines from passing through the Channel.

By November 1918 two towers were almost complete and two more were under construction but the War was now over and they were anchored off Shoreham where they became a hazard to shipping. Eventually a use was found for one of them as a replacement for the Nab lightship in the English Channel, near the Isle of Wight. In 1920 the 61 metres high tower was towed out to sea and submerged into position.

Shipping losses during the War and a shortage of steel forced ship owners to consider reinforced concrete (or ferro-concrete as is was then known) as an alternative. Many canal and sea-going barges were built all over the country, some of which are still afloat. They often had names beginning with Crete, such as Creterock.

The SS Armistice, launched at Barrow-in-Furness in January 1919, was the first self-propelled concrete ship to be built in Britain. It traded between Liverpool and Lagos for more than 25 years before being stripped of its machinery and converted into a floating warehouse at Luanda, Angola, where it remained until 1969 when it was towed out to sea and scuttled.



In an effort to obtain early warning of enemy aircraft, two 3.75 metre dishes were constructed on the Kent coast in 1917. The smoothness and rigidity of the semi-circular concrete linings reflected the sound of approaching aircraft. In May 1918 they helped the Air Force track and shoot down seven out of 22 German bombers during the last mass air raid of the war on London. More dishes were built during the 1930s but radar proved to be more reliable and their use was discontinued.

During the Second World War prestressed concrete was used by the Germans for defence work in Europe, in particular for the roofs of U-boat pens, which were up to 8 meters thick. In Britain some precast concrete railway sleepers were made, but production started seriously only after the war.

Reinforced concrete was also put to many uses during the Second World War, including air-raid shelters, huts for military camps and aircraft runways. But it is perhaps best known for its use in the caisson units that went to form the famous Mulberry Harbour, which played a vital role in the D-day landings leading to the liberation of Europe.

As all the existing harbours in France were in enemy hands, a plan was made to construct a harbour wall in sections in Britain, which could be floated across the Channel and submerged into position. It consisted of 200 concrete pontoons, each 61 metres long by 18 metres deep and 18 metres wide that were towed across during one night.

1 Nab Tower, English Channel, 1920
Originally designed as one of a chain of anti-submarine devices, this tower now serves as a navigation aid for shipping.

2 Concrete block houses, Braintree, Essex, 1919
With thousands of troops returning from Europe in 1918 the Prime Minister, Lloyd George, began building "homes fit for heroes". They were constructed entirely of concrete and were the first in the UK to be built to metric sizes.

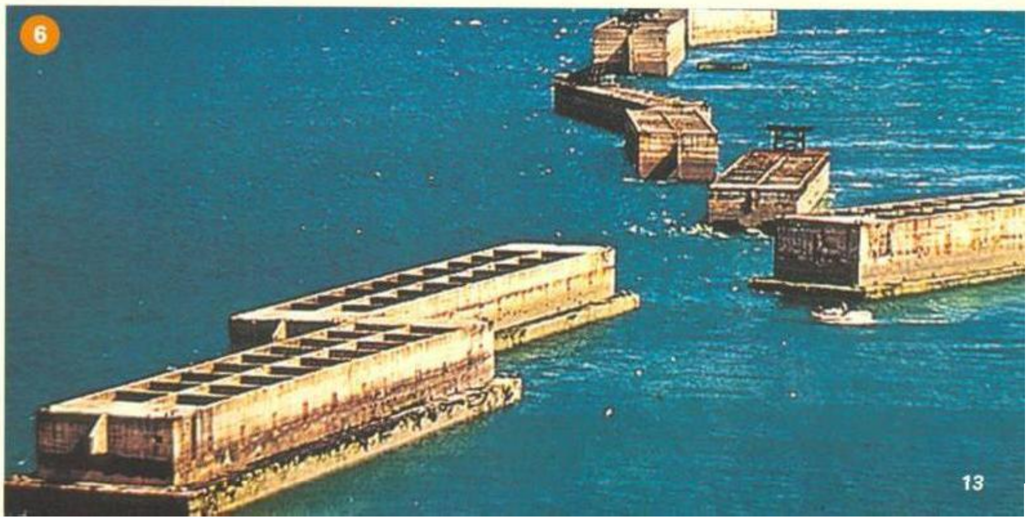
3 SS Armistice, 1919
The first self-propelled concrete ship built in Britain, this was in use in Angola until 1969. It was 63 metres long and could carry 1150 tons of cargo. The concrete construction resulted in less vibration than that in steel ships.

4 Early warning system, Kent Coast, 1917
Britain's first early warning system against enemy air attack began with concrete 'ear trumpets'. They worked successfully towards the end of the First World War, but were superseded by radar for the Second World War.

5 Air-raid shelters
Putting the finishing touches to a concrete shelter against enemy bombing raids.

6 Mulberry Harbour, 1944
These concrete caissons were made in several ports in southern England, towed across the Channel and sunk to provide an artificial harbour for ships supporting the Allied invasion of Europe. Many of the units can still be seen lying offshore at Arromanches, Normandy and some in Portland Harbour this side of the Channel.

There was also a resurgence of interest in reinforced concrete boats, again owing to the shortage of steel caused by shipping losses. A few coasters and hundreds of barges were built between 1941 and 1945, while many larger, sea-going vessels were built in America.



1945 – 1965
Rebuilding Britain

The rapid reconstruction of houses, bridges, factories and schools destroyed in the war was the main challenge facing the construction industry in Britain from 1945 onwards, when skilled craftsmen and some structural materials (steel and wood) were in short supply.

For housing, this resulted in the erection by 1948 of 40,000 'prefabs' - prefabricated single-storey houses, many built of asbestos cement, which were intended as temporary accommodation.

Following this, systems for building permanent low-rise housing from prefabricated reinforced concrete elements were developed, and used until the 1960s. In 1958, precast concrete cladding was used for high-rise reinforced concrete flats at the London County Council's Alton East Estate in Roehampton.

The expansion in the use of precast concrete in the early 1960s resulted in the development of many industrialised building systems for houses and flats. Prefabricated wall, floor and roof units were factory-produced and assembled on site with the minimum amount of labour and effort. With the urgent need to rebuild most of Europe's shattered cities after the war it seemed the most logical method of building, and by 1965 there were over 230 systems available in Britain alone. But their popularity was short-lived, and the high-rise blocks were usually not liked by the residents.

At this time, bridge designers were also obliged to make use of reinforced and prestressed concrete as an alternative to steel. One tonne of prestressing steel can result in 15 times the amount of building that is made possible by one tonne of structural steel.

Britain's first precast prestressed concrete railway bridge was the Adam Viaduct in Wigan, built in 1946. It was followed soon after by Nunn's Bridge at Fishtoft in Lincolnshire, which was the first in-situ prestressed concrete bridge in Britain, and used the Freyssinet system. Prestressed concrete quickly became the dominant material for all bridges, except those with very long spans where a steel suspension bridge was the answer.

The growth of roads, by-passes, elevated urban roads and motorways was a major feature of this period, and concrete was the dominant material used in their construction. Major engineering projects included the Hammersmith Flyover in 1961 in West London. Meanwhile a start was made on the motorway network with the opening in 1958 of the 8-mile long Preston Bypass, the start of the M6. This was followed in 1959 by the first 70-mile stretch of the M1. Both of these were made of concrete, as were many of the associated bridges.

Turning to industrial uses of concrete, 1951 saw the construction of a factory in Brynmawr, south Wales, remarkable for its nine reinforced concrete shell domes that covered its large clear production floor.

An example of the spectacular use of sweeping reinforced concrete arches was the Stockwell Bus Garage in London. Finished in 1953, it provided a clear space some 116 by 60 metres for 200 buses to park and manoeuvre.

One of the urgent tasks in this post-war period was the construction of schools to take the influx of children following the post-war baby boom. An example is Kidbrooke Comprehensive School near Greenwich, built in 1954.

1 Alton East Estate, Roehampton, London, 1958
One of the most talked about housing schemes in the world in the late 1950s, the high-rise blocks are faced with white precast concrete cladding.

2 Nunn's Bridge, Fishtoft, Lincolnshire, 1947
Britain's first in-situ prestressed concrete bridge.

3 The Hammersmith flyover, West London, 1961
This precast prestressed viaduct was buil in 20 months with practically no disruption of traffic.

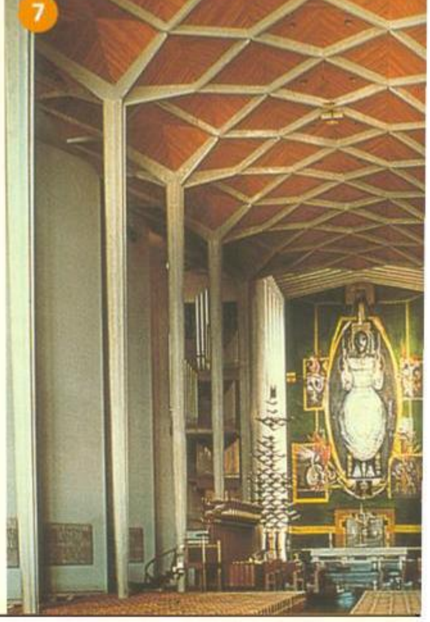
4 Factory, Brynmawr, South Wales, 1951
Described as one of the most important post-war industrial buildings, this listed factory now lies derelict.

5 Stockwell Bus Garage, London, 1953
An example of architecture meeting engineering, this huge bus station house 200 new buses that replaced trams afte the War.

6 Kidbrooke School, Greenwich, London, 1954
Constructed almost entirely of reinforce concrete, this school provided magnific facilities for 2000 girls.

7 Coventry Cathedral, 1962
The nave canopy is supported by 14 elegantly tapered prestressed precast columns made with light blue-grey concrete. These rest on metal bases tha are only 6 cm square.

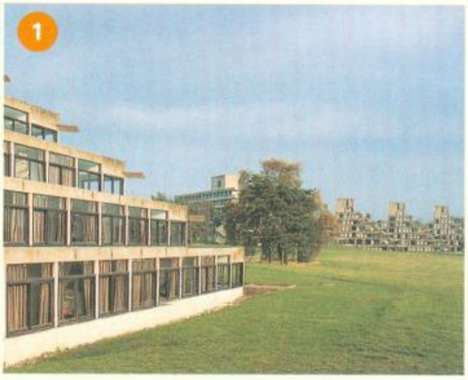
Completed in 1962, Coventry Cathedral is one of the most poignant reminders of the futility of war - it is linked to the bombed-out ruins of the previous cathedral. Although the exterior is stone clad, the rest of the structure, even the altar, is concrete.



1965 onwards

Towards today

The late 1960s saw a continuation of the need to cater for the post war 'baby boom' and concrete played a major part in accommodating the influx of students to universities and colleges. One much-acclaimed project was the new University of East Anglia.



In the early 1970s attention was focused on the appearance of concrete. There was a need for it to recover from its somewhat unfortunate image that had developed over the previous decade. 'Building in harmony' became all the fashion, culminating in the European Architectural Heritage Year, 1975.

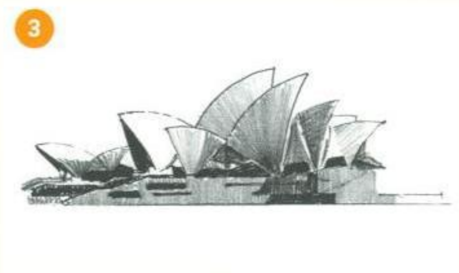
Merging the buildings of the 20th century with those of our proud past enriched many of our historic town centres. Concrete, with its versatility, was able to grow to meet this challenge and so became one of the finest construction materials of the century. An example of note is to be seen on The Promenade in Cheltenham. Here an old cinema was pulled down and a new office block erected to match the adjacent Regency style municipal offices.

The past 35 years have also seen considerable advances in civil engineering. The quest for oil resulted in the construction of complex production platforms for use in the North Sea, in which concrete again played a major role. These platforms (see page 28) involved advanced techniques in both their design and construction, which ten years earlier might have seemed almost inconceivable.

In 1978 the pumped storage hydro-electric scheme at Dinorwic in North Wales was one of the largest civil engineering contracts undertaken at that time in Europe. A mountain was hollowed out to provide a turbine hall so huge that it could accommodate a cathedral complete with its spire. This cavern, together with a maze of tunnels, was lined with concrete, which was also used for much of the structural work (see page 28).

Another large contract was the multi-million pound scheme to protect London from flooding as a result of a surge tide flowing up the River Thames. The Thames Barrier, pictured on page 22, was built across the river at Woolwich Reach in 1985. Its massive gates can be raised into position from the riverbed to prevent flooding.

The increase in road use since 1965 has resulted in two major features of construction: the continued growth of the motorway network with its accompanying bridges and elevated sections, and the increase in multi-storey car parks. Concrete has been the material chosen for the majority of this work.



After the war the use of ready-mixed concrete grew at a vast rate, so that by 1970 it was well on its way to being used for most in-situ concrete work, supplied by truck-mixers from a network of local plants.

The construction of the Channel Tunnel (see page 18) with its English and French terminals has been described as the greatest engineering achievement of the 20th century. The total tunnel length is just under 32 miles, and the English half is lined with some 1/2 million precast concrete segments weighing up to 8 tonnes. Enough concrete was used in the tunnels to fill Wembley Stadium to the height of the Blackpool Tower.

A major factor over the years has been the increase in the strength of concrete and this has influenced design by allowing taller, longer and yet lighter structures. The emphasis has now switched to durability issues, and the concept of whole-life costing, that is the construction cost of the structure plus its cost in use. This has resulted in increased importance being given to the cost of repair, the energy used and projected years of service. Concrete scores well when all these are taken into account.

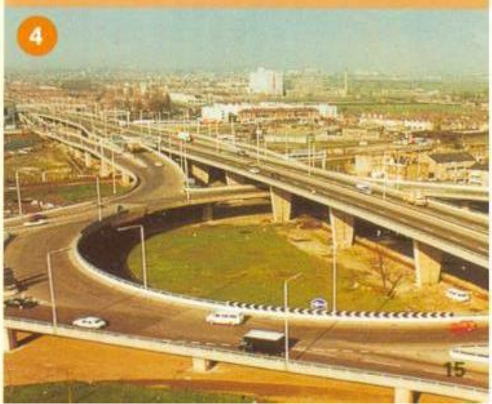
1 University of East Anglia, 1967
A precasting yard was set up on site to produce the units for these terraced accommodation blocks that overlook the park and lake and were very popular with the students of the time.

2 Building in harmony, Cheltenham, Gloucestershire, 1987
A precast concrete façade was used on the RoyScot Trust headquarters to match the adjacent 1839 Regency buildings on Cheltenham's famed Promenade.

3 Sydney Opera House, Australia, 1973
Perhaps the most famous building in the world, the distinctive shell roofline owes much to the UK engineers, Ove Arup & Partners. Here is technological achievement in the service of art.

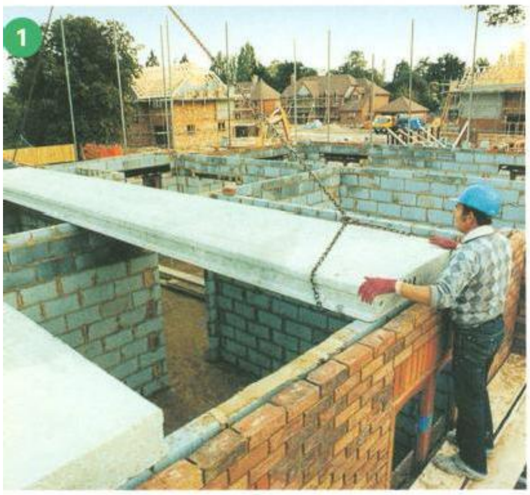
4 Motorway interchange, 1977
This large multilevel interchange on the M40 near White City relies heavily on concrete.

The remainder of this publication is devoted to the modern use of concrete in the United Kingdom.



Housing

Ease of construction, economy and its thermal and acoustic properties are among the reasons that concrete is chosen for building houses and flats today.



Concrete is used everywhere from the top to the bottom of houses. Most architects and builders now choose concrete roof tiles or fibre cement slates for building new houses and for re-roofing. Foundations for houses - as for virtually every other type of building - are made of concrete.

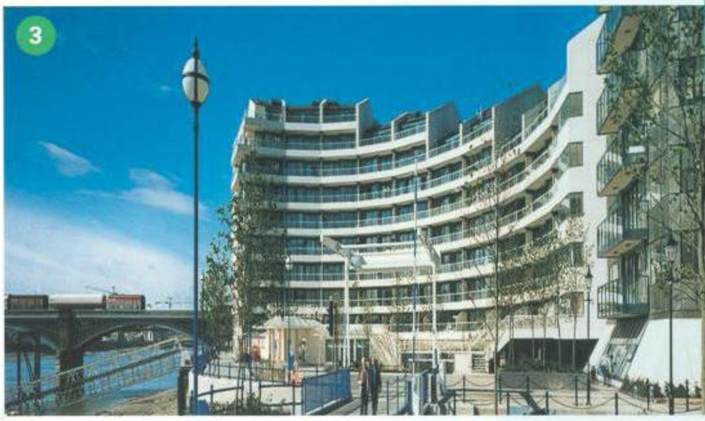
Good thermal insulating properties make concrete blockwork an inexpensive method of reducing heat loss through the inner leaf of a cavity wall and its sound-insulating characteristics mean it is an obvious choice for floors and internal walls, within and between dwellings.

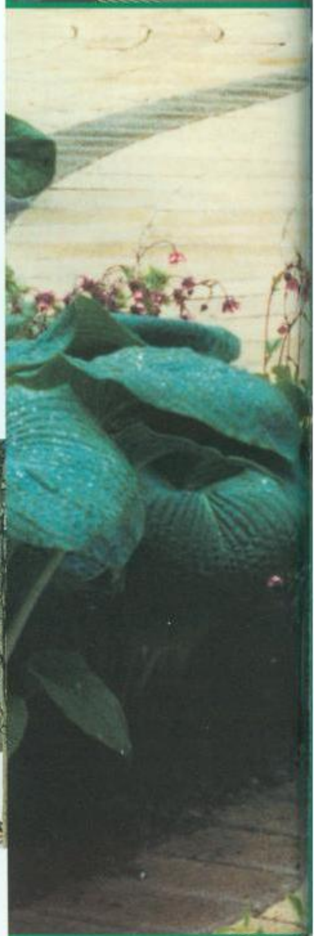
Speed of construction is the reason that most multi-storey apartments are built with concrete masonry and reinforced concrete frames and floors, which provide the added benefits of fire resistance and sound insulation.

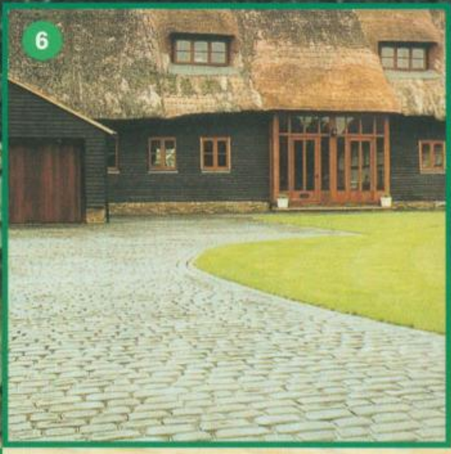
There is a range of concrete wall finishes, enabling new or refurbished homes to blend in with their neighbours. Outside walls can be built of attractive concrete bricks or blocks, or of insulating blocks that can be simply rendered and painted.

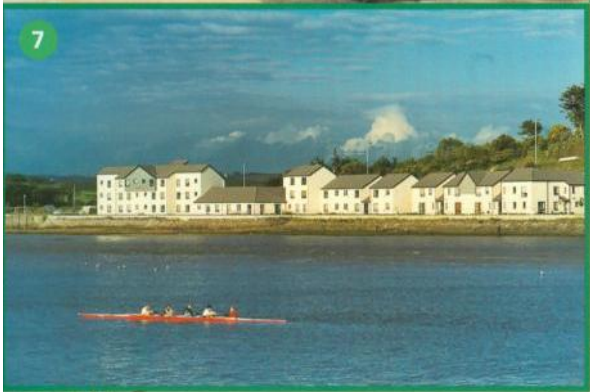
Concrete is the main material used to satisfy the increasing demand for basements within new houses; these provide extra accommodation and storage without increasing the use of land, and are well insulated by the ground.

In the garden, concrete offers a comprehensive choice of materials for drives and parking areas, ornamental walling, paving, ponds and swimming pools. Many of these features can be built by a competent do-it-yourself enthusiast.









1 Constructing a modern house

Lightweight concrete blocks are used for internal walls and the inner leaf of outer walls. Here, the first floor concrete slabs are lowered into position.

2 'Victorian' Edinburgh

These luxury apartments in the heart of Edinburgh are faced with concrete blocks chosen to match the neighbouring Victorian houses.

3 Chelsea homes and offices

Built as part of the exclusive Chelsea Harbour development providing homes, shops and offices for over 4000 people, the flats were sold as bare shells, in which each buyer could decide where the partition walls and fitments were positioned.

4 Additions to an Edwardian mansion

A swimming pool and garage block was added to an Edwardian mansion in Oxfordshire in a style that blended beautifully with the existing buildings.

5 Climbing the hill

Concrete was used on a derelict and steeply sloping site in Bristol to create a smart crescent of townhouses with a period look to it.

6 The right approach

A pattern imprinted concrete drive that simulates cobbles was chosen to complement this converted barn.

7 Clad against the elements

Painted rendering over concrete block walls stands up well to the elements in this coastal development in Bideford, Devon, built as sheltered housing.

8 Hidden energy efficiency

Behind the period look of this development in Midhurst, Sussex, is an energy-efficient construction using concrete blockwork and insulation.

9 A basement adds that extra room

More living or storage space is added to this house by including a basement, the use for which can be varied as the life style of the family changes.

10 Adding style to the garden

Concrete paving is used to add a strong design element to this garden and provides a good foil for the planting.

Travel and transport

Whatever our chosen method of transport - land, sea or air - concrete contributes to our journey. We find it in roads, safety barriers, rail tracks, pedestrian precincts, ports, harbours, tunnels and airports.

Modern jointless road construction techniques, coupled with the use of 'whisper' low-noise concrete and a long, rut-free life have led to the increasing use of concrete for road surfaces, bases and sub-bases.

Concrete withstands heavy loads and needs little maintenance, and because of its resistance to oil is increasingly used as blocks for parking areas and service station forecourts.

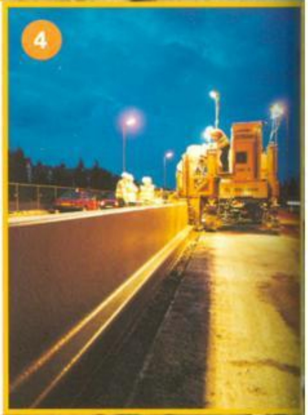
A feature of modern railway design is the hard-wearing concrete sleeper, which has taken over from its timber forerunner. Appearance, economy and durability have also prompted the railways to use concrete paving for platforms, forecourts and other public areas.

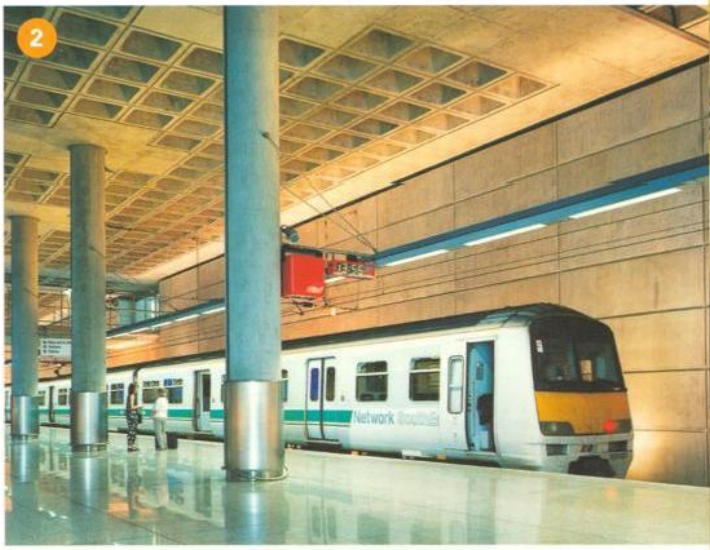
Seagoing passenger and freight companies have followed suit, making good use of concrete around harbours and at ferry terminals and hoverports.

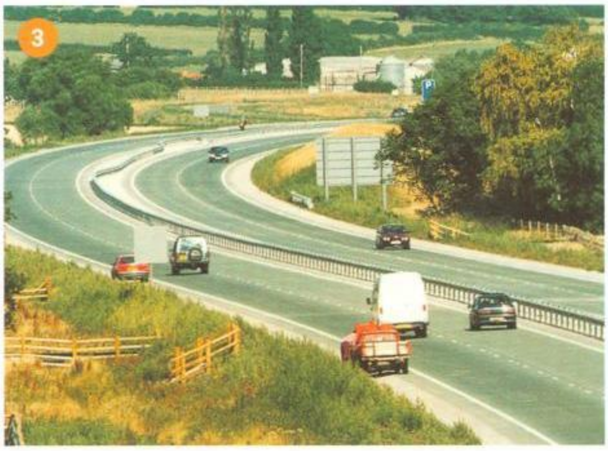
An aerial view of London's Heathrow airport makes it clear how much concrete is used in air transport facilities. Most British airports rely on the structural strength of the material for taxiways, hard-standings and runways, as well as for terminal buildings.

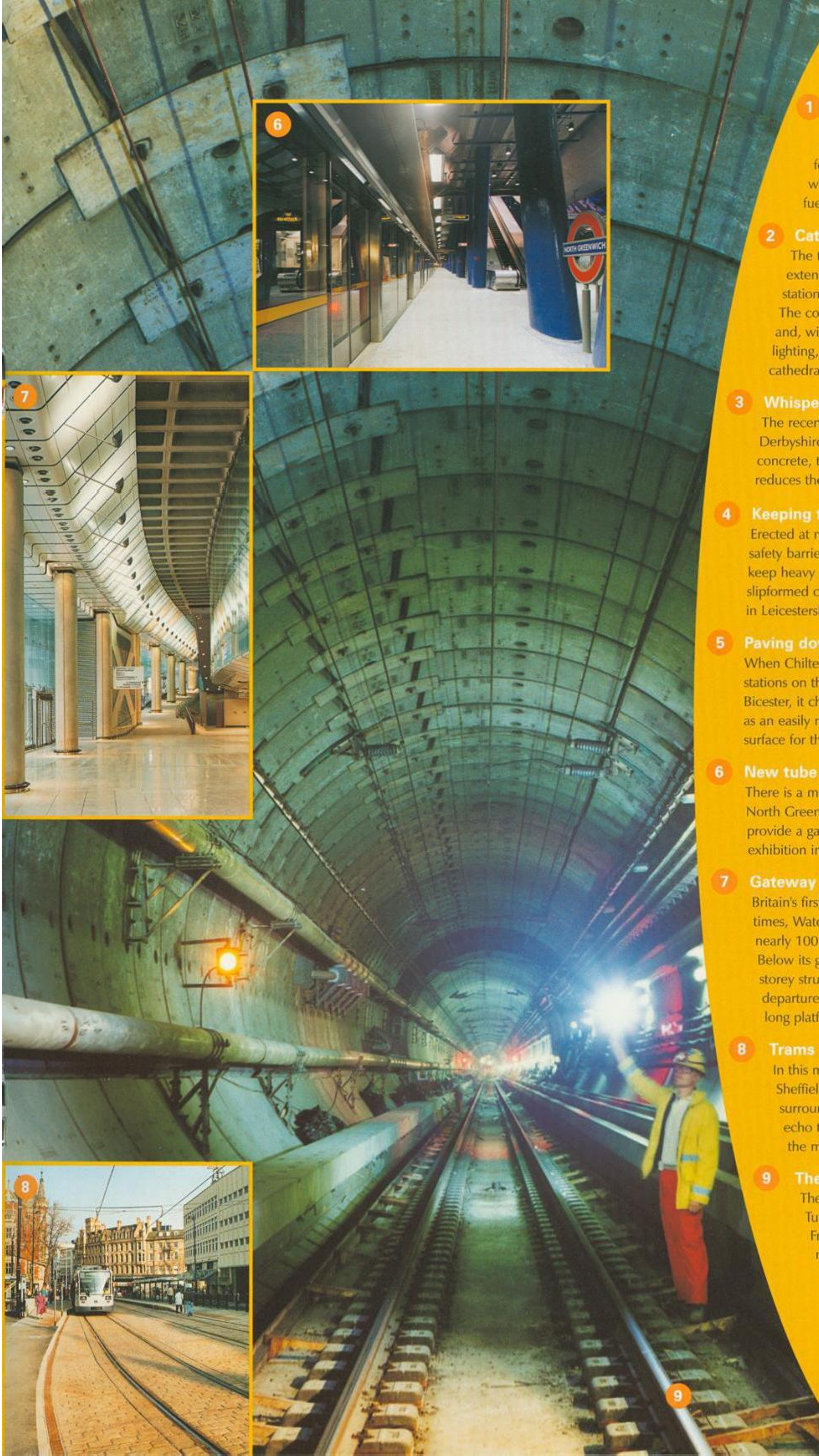
Turning to below ground connections, a major project of the 1990s, the Channel Tunnel, relies heavily on concrete for both the tunnel lining and the terminal at Folkestone.

Also below ground, the Jubilee Line extension was built to take visitors to the Millennium Dome at Greenwich via a string of light, airy stations built of concrete.









1 Happy landings
London's Heathrow Airport typifies the use of concrete for taxiways and hardstandings where it resists damage from fuel spillage and possible fires.

2 Catch the train to the plane
The terminal at Stansted Airport is extended to form the roof to the station, which is 12 metres high. The concrete has been left exposed and, with the carefully chosen lighting, produces an almost cathedral-like atmosphere.

3 Whispering along
The recently completed A50 in Derbyshire is made of 'whisper' concrete, the new road surface that reduces the noise from tyres.

4 Keeping the traffic apart
Erected at night to quickly provide a safety barrier that is tough enough to keep heavy motorway traffic apart, this slipformed concrete barrier is on the A46 in Leicestershire.

5 Paving down the line
When Chiltern Railways refurbished its stations on the line from Marylebone to Bicester, it chose concrete block paving as an easily maintained and attractive surface for the platforms.

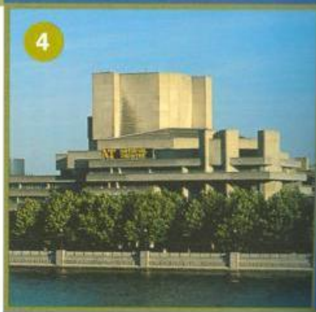
6 New tube for the Millennium
There is a modern feel to the colourful North Greenwich station that will provide a gateway to the Millennium exhibition in Docklands.

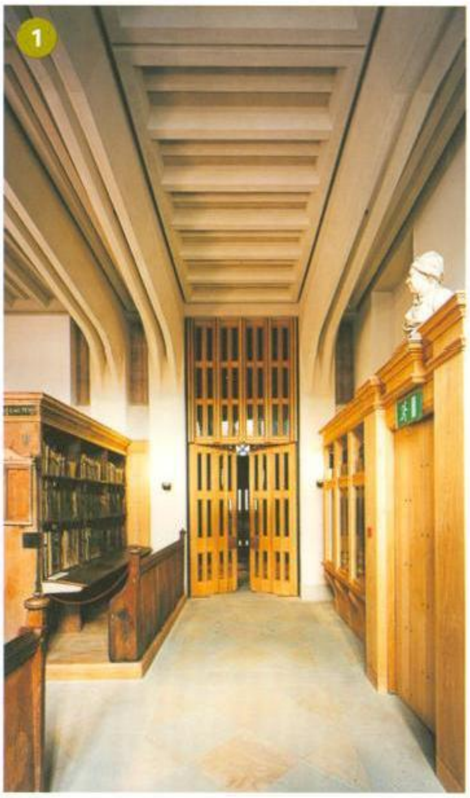
7 Gateway to the Continent
Britain's first new station since Victorian times, Waterloo International used nearly 100,000 tonnes of concrete. Below its glass and steel roof is a triple storey structure housing arrival and departure halls and five 400 metre long platforms.

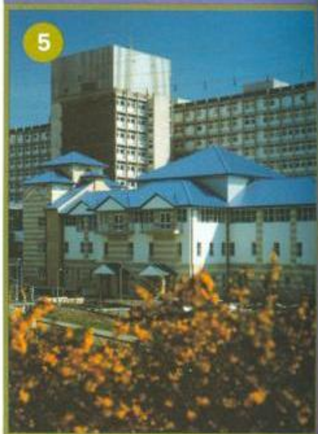
8 Trams go back to yesteryear
In this modern development in Sheffield, the trackbed and surrounding area are designed to echo the time when trams were the major form of transport.

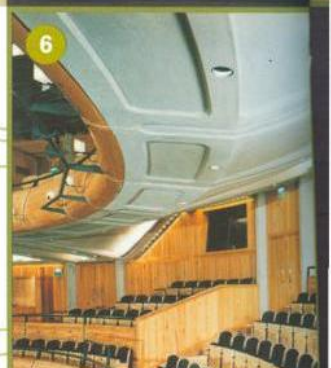
9 The French connection
The construction of the Channel Tunnel, with its English and French terminals, was the most breathtaking project of the 20th century. The whole tunnel is lined with precast concrete segments.

Serving the community









Concrete provides good value for money in health and education buildings, and its resistance to fire is an added bonus for places that are used by large numbers of people.

Noise, vibration, heat and even x-rays can be contained by concrete structures to give a pleasant, safe and peaceful environment. This is especially useful in hospitals, where concrete's thermal mass helps to reduce fluctuations in temperature.

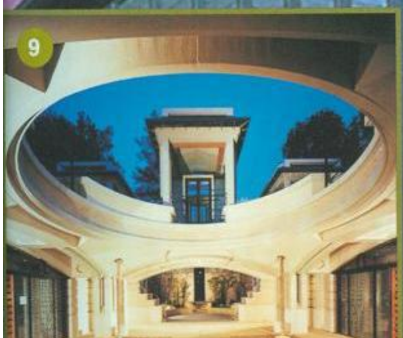
The use of concrete is also appropriate for many of the ancillary buildings associated with major educational complexes - swimming pools, theatres, sports halls and outdoor games courts all make use of the material.

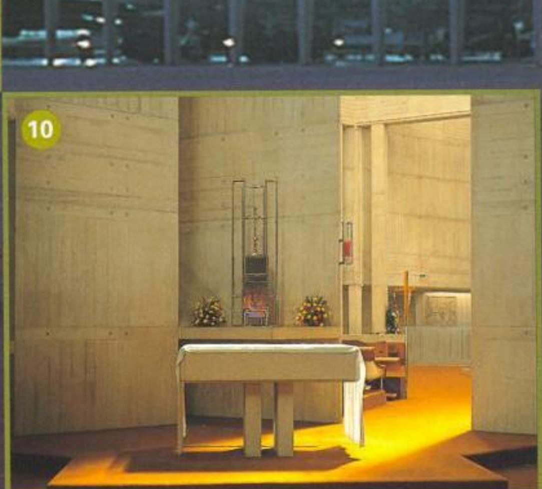
Sports complexes and spectator stands depend heavily on concrete's toughness and structural strength. Its water resistance makes it widely used for swimming pools, marinas and other water sport facilities. Indoor and outdoor sports surfaces are often laid on concrete bases.

Libraries and other archives are often housed in concrete, which can be used to provide light, airy places of study or secure storage where the temperature is kept constant with help from concrete's thermal mass.

The arts are well served by concrete, which is used to house theatres, museums and galleries. Its thermal mass helps maintain an even temperature in these buildings, where the design often reflects the flexibility of form that is provided by concrete.

The similarity of mass concrete to natural rock and the ability to cast it to simulate carved stone make it especially suitable for creating places of worship, where it can be used to provide an appropriate atmosphere.





1 A secure home for the world
Built to house the Mappa Mundi - the only large-scale gothic map of the world - this building was designed to complement the adjacent Hereford Cathedral.

2 Britain's oldest museum collection
The new Royal Armouries Museum in Leeds was built to re-house part of Britain's oldest museum collection from the Tower of London.

3 Housing antiquity
The British Museum extension is designed to complement the collection, which ranges from massive sculptures to small treasures.

4 Brooding over the Thames
The South Bank Arts Centre houses a complex of theatres, concert halls and art galleries, and is an example of massive concrete at its most magnificent.

5 Built for babies
The human scale of the Maternity Unit strikes an appropriately domestic note in comparison with the multi-storey general wing at Ealing Hospital.

6 Built for sound
The new opera house at Glyndebourne was designed to exclude aircraft noise while providing the correct acoustic qualities within. The concrete ceiling has a built-in sparkle provided by micaceous sand.

7 New balls, new court
The new No. 1 Court stadium and broadcast centre was the first phase in the redevelopment of the tennis facilities at Wimbledon - home of British tennis.

8 Rejuvenating the Belfast riverside
The Waterfront Hall, Belfast, makes its mark as a state-of-the-art public building providing conference and concert facilities.

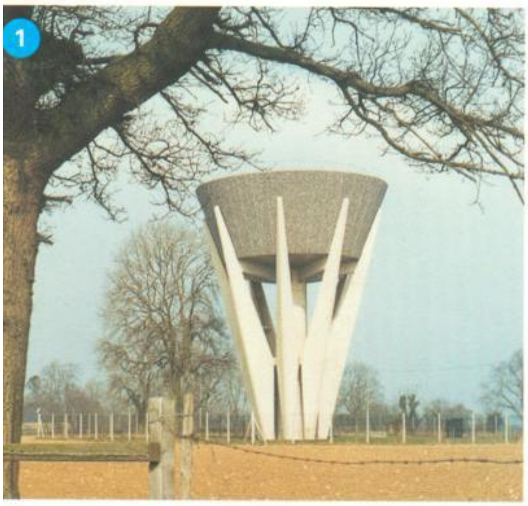
9 Peace below ground
The garden quadrangle at St John's College, Oxford, is set below ground level to house the public spaces.

10 A monument in concrete
The strength and timelessness of unpainted concrete creates a fitting ambience at Clifton Cathedral, Bristol.

11 Flights of fancy
The American Air Museum at Duxford provides a large clear dome to hold a massive B-52 bomber and many other vintage planes.

Water

Concrete's good performance make it a natural choice wherever water has to be collected, contained or controlled.



Almost two-thirds of the dams built in Britain since 1950 are of concrete, which is also widely used to construct reservoirs.

Concrete is the major material used for elegant water towers, which provide some of the country's finest landmarks and provide consistent pressure for distribution through the local water supply network.

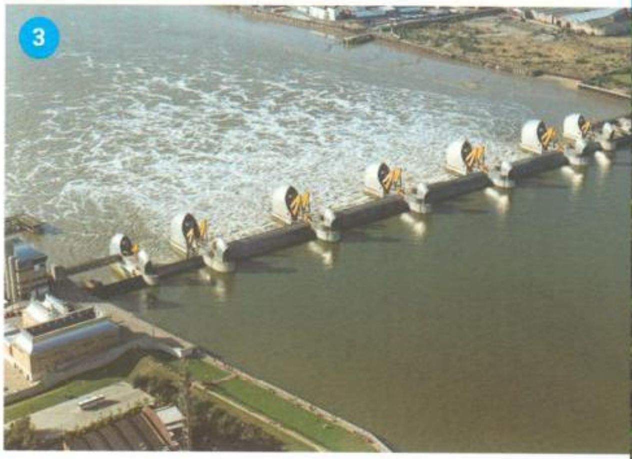
Concrete has an equally important role to play in underground drainage systems, and for the treatment and supply of fresh water throughout the country. It is a major material in the construction of sewage treatment works and is used to repair and replace old crumbling sewers.

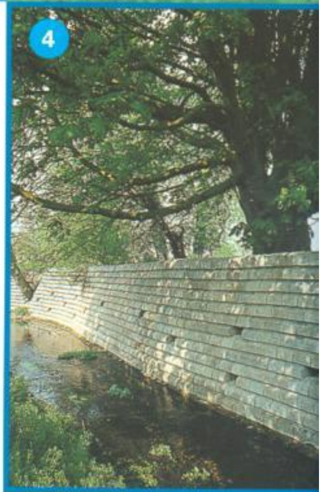
Its contribution to water-based leisure activities continues to develop. Britain's canal network is being restored and here concrete has proved to be a good substitute for traditional stone. Rivers passing through built-up areas are contained by concrete walls that are often designed as a decorative feature.

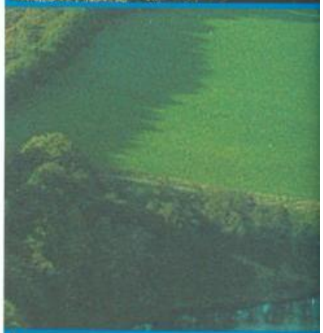
Where the coastline or river banks need defending, concrete's durability comes into its own. It is used in various ways around Britain's coasts where the sea threatens to erode the shoreline. Concrete groynes and sloping sea walls disperse the force of the strongest waves before they hit the land. Wave energy is also reduced by concrete deflectors around harbour walls and marinas.

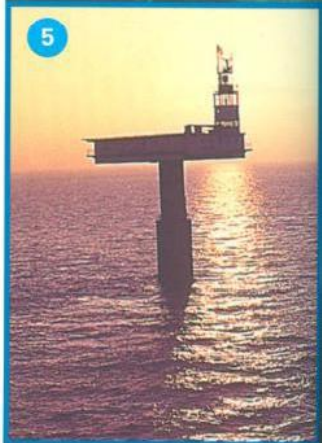
London is protected against tidal surges moving up the Thames by the massive Thames Barrier, which can be raised to stop the flow but is normally kept lowered to allow the passage of ships.

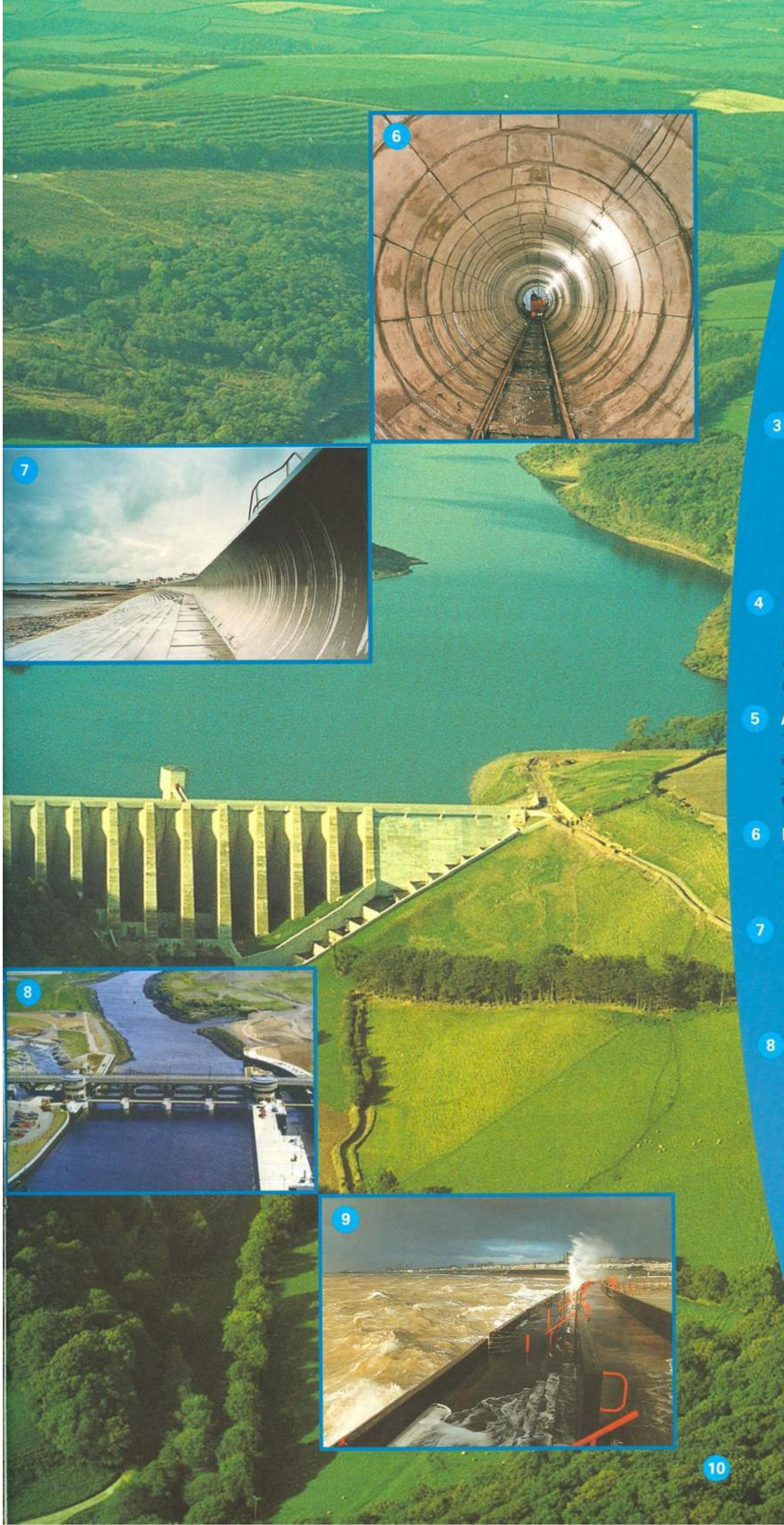
Moving out to sea, concrete's massive strength makes it the choice for light towers around the coast to warn ships of hazards. It is also the choice for some self-build yachts, and provides a tough, easily repaired hull.











1 Keeping up the pressure

Two colours of concrete were chosen for this water tower at Baydon, which provides a distinctive landmark in the Wiltshire countryside.

2 Casting off in concrete

The Rula, seen here in a regatta in the Solent, is 9.5 metres long. Built by her owner, she is traditionally rigged and her smooth ferro-cement hull is indistinguishable from wood or fibreglass.

3 Keeping London safe

The Thames Barrier, built to prevent tidal surges flooding London, much of which lies below sea level. Concrete was used for the massive piers sunk into the chalk below the riverbed, between which are the gates that are raised when required.

4 A helping hand on the bend

Bank erosion on a Cambridgeshire stream has been successfully overcome with interlocking precast concrete wall retaining units.

5 A warning light in the night

The Royal Sovereign Light Tower stands in the English Channel. It was built on land, and towed out to its position near Brighton to warn shipping of the coastal hazards.

6 Ring of bright water

Twice as long as the Channel Tunnel, the London Ring Main carries half the water supply for one of the world's major cities.

7 Turning back the waves

The sea defences at Burnham-on-Sea, Somerset, include a new promenade protected by one of Britain's largest wave return walls.

8 Freshwater development

The River Tees Barrage impounds the river to provide a freshwater stretch for high quality waterside developments. On one side of the barrage is a navigation channel with a lock, and on the other a white-water canoe slalom course.

9 Standing up to the storm

The rugged sea wall at Brighton protects the marina from the worst that the Channel can throw at it.

10 Keeping water in reserve

Built to supply drinking water for the surrounding area, Wimbleball Dam in Somerset is also used for recreation.

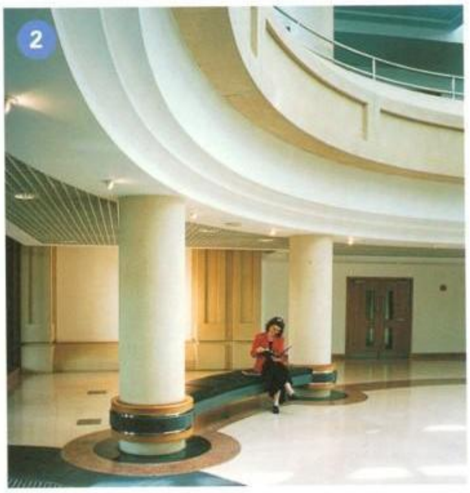
The world of work

Building in concrete provides quick and cost-effective construction in the competitive commercial world. Offices, hotels and other business premises can be completed within tight time schedules and to budget.

Most commercial and administrative buildings have concrete foundations, stairwells and lift shafts but increasingly the frame (i.e. the walls, columns and floors) is likely to be of concrete. This is often left exposed and its thermal mass helps moderate the temperature. Internal walls may be of concrete blockwork and the exterior may feature architectural concrete cladding.

Communications are a major growth industry and for telecommunication towers that need to contain heavy equipment, concrete provides the ideal solution. Underground ducting carrying vital cable links also uses concrete as a protection against damp and corrosion.

In the town centre, concrete is apparent in multi-storey car parks, and for those built underground, and in pedestrianised shopping centres where attractive block paving is found underfoot. Many shops and offices are likely to have a concrete frame, perhaps faced with bricks to match the surrounding style.



Concrete blocks are to be found at bus stations and in industrial areas, including docks and harbours where heavy-duty service is required.

Factories and warehouses take advantage of strong concrete foundations and hard-wearing floors that can take the load, while columns withstand the knocks.

Farmers, too, have turned to concrete for a range of agricultural facilities, including milking parlours, silos, storage buildings, yards and roads to provide all-weather access for heavy vehicles.

1 The human face of the law
The warm tones of the concrete blockwork inside and out make the Croydon Law Courts an imposing yet sympathetic place to visit.

2 For the record
The Public Record Office at Kew has a concrete core to withstand the exceptionally high floor loading associated with this type of use.

3 Imposing entrance
This imposing office block in Slough features precast concrete pillars.

4 Taking the fear out of parking
The long clear spans and good lighting encourage shoppers at the Lakeside Shopping Centre near Thurrock in Essex.

5 Shopping in style
The Harlequin Shopping Centre provides a bright and comfortable retail environment for Watford.

6 Standing up to farming
A versatile farm building with a floor that can stand up to all that farming throws at it.

7 Research in style
Three floors of research laboratories are housed in this precast concrete and glass building at the Cambridge Science Park.

8 Tilt up for speedy construction
Construction of this mixed factory and office facility at Glenrothes in Scotland was speeded up by casting the wall panels on the ground and then tilting them into position with a crane.

9 Clad in contrasts
Vauxhall Cross in London is stepped back from the Thames in a manner that is reminiscent of ancient Babylon. It is clad in precast concrete and glass.

10 Justice with majesty
The white finish to the walls a gives a somewhat imperial air to the Truro Courts of Justice.

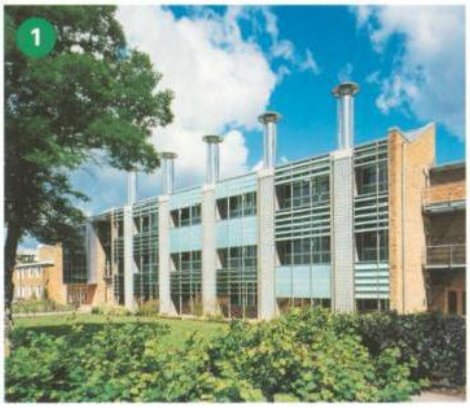
11 Concrete takes the strain
Heavy duty block paving stands up to the loads encountered on the dockside at Felixstowe.

12 Concrete for the night
The precast frame and cladding for this new hotel in London's East India Docks was built in just nine weeks.

13 Opening up the news
The ITN headquarters in London features an eight-storey central atrium surrounded by open-plan offices.

Care for the environment

When used in buildings and structures, concrete is an environmentally friendly material. It generates no emissions, needs no toxic preservatives, and is inherently resistant to fire.

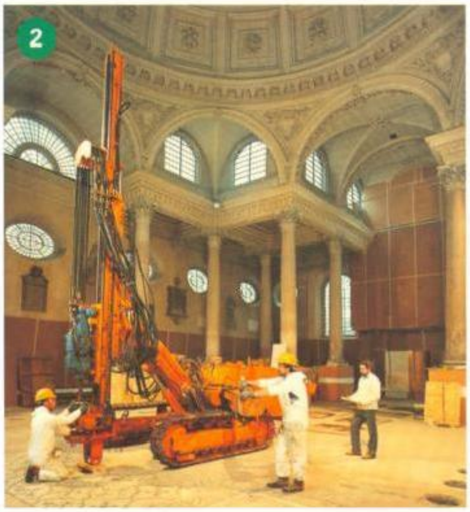


When used in buildings, concrete's thermal capacity - the ability to absorb and radiate heat - makes it easier to control the temperature, and to reduce or even eliminate the need for expensive air-conditioning. This reduces energy consumption and so enhances sustainability. In addition to this, lightweight concrete blocks are used in many buildings for their insulation properties.

In Britain there is a great shortage of unused land for development. Where a brownfield site has been affected by previous industrial processes, the contaminants can be effectively locked into a cement stabilized zone and the site safely used for redevelopment.

Cement can also be used to stabilize nuclear waste, turning it into solid blocks that can be stored safely for many years until it is considered to be harmless.

In the field of recycling, cement and concrete come into their own. Worn out road surfaces can be pulverised, mixed with cement and water and then compacted to provide a new road, without the need to dispose of the old surface or bring in new material.



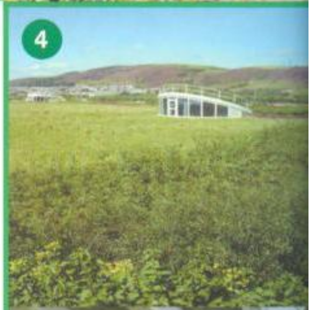
Likewise, concrete rubble from demolition sites can be used as the sub-base for new roads and as aggregate for making new concrete, so reducing the amount of new aggregate required.

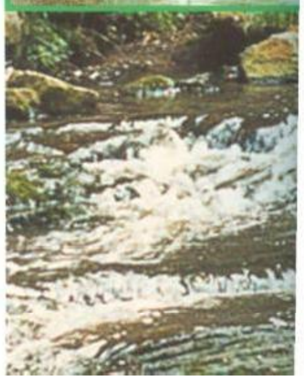
Concrete is the natural choice for filter beds and wastewater treatment plants, which are now beginning to be built below ground so as not to impinge on the above-ground environment.

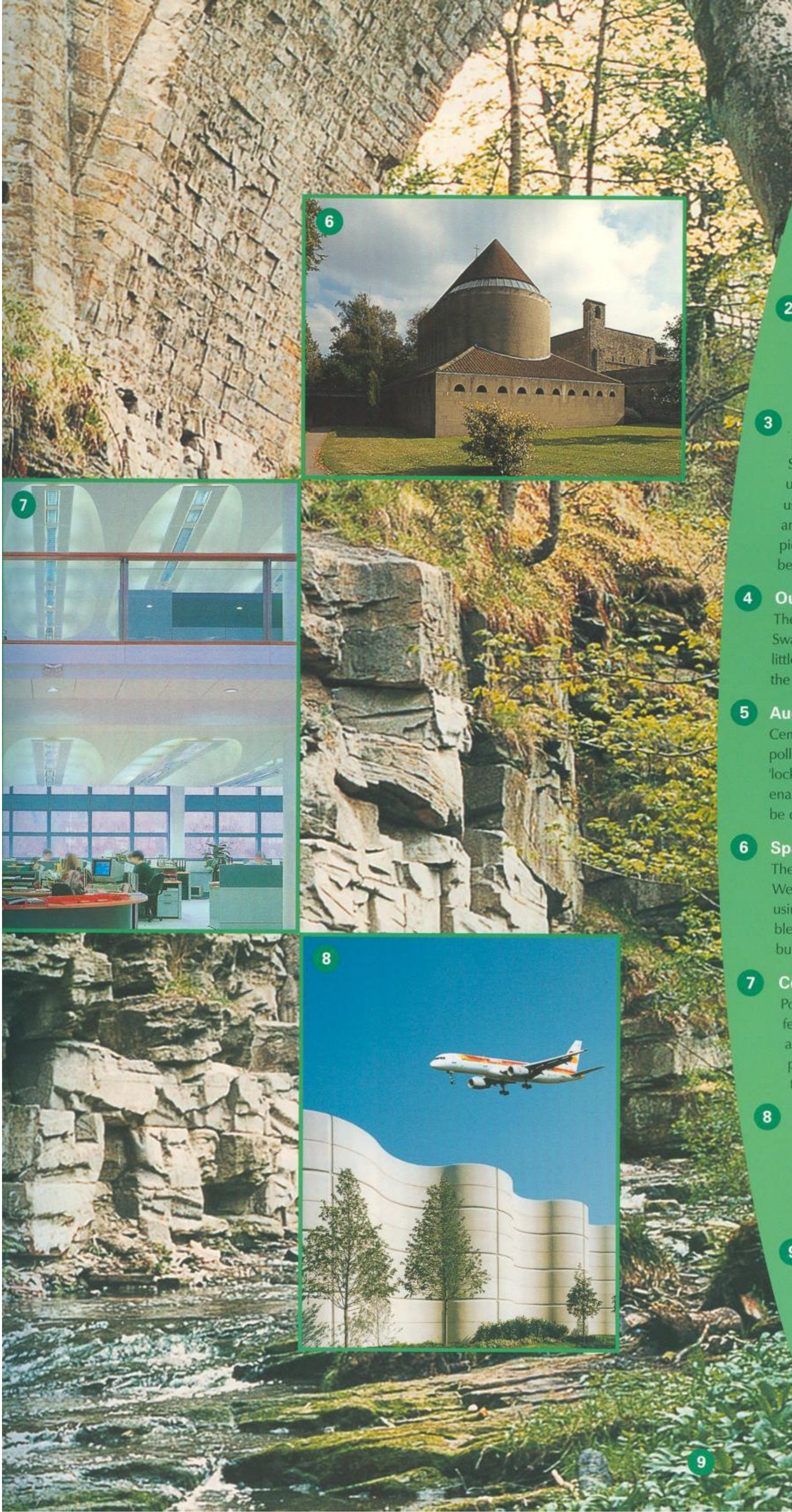
Noise is another pollutant, and here concrete is particularly efficient at reducing noise transmission between and within domestic buildings and, on a larger scale, at airports and beside motorways.

New buildings can be made from concrete that is carefully matched with the style of older buildings, so avoiding a clash between the old and the new.

Concrete can be used to preserve and protect our heritage by underpinning or repairing structures that are unstable or in danger of collapse.







1 Air-cooled naturally
The New Environmental Office built at the Building Research Establishment is designed to vent warm air naturally while drawing in cool air. It was one of the first buildings to use crushed recycled concrete as aggregate for the new concrete.

2 On firmer foundations
The future of St Stephen Wallbrook, one of Wren's masterpieces, has been secured by concrete piles sunk 20 metres into the London clay.

3 Second time around for roads
Recycling the A3088 near Yeovil in Somerset. The old road surface and underlying layers have been pulverised using specialist equipment. Cement and water have been applied, and the picture shows materials being mixed before being compacted and resurfaced.

4 Out of sight, out of mind
The wastewater treatment plant at Swansea is sited below ground with very little appearing at the surface to interrupt the view of the countryside.

5 Auguring well for the future
Cement slurry is injected into the polluted ground, which will set hard, 'locking in' the contamination, and enabling this brownfield site to be developed.

6 Spanning the centuries
The church at Saint Mary's Abbey in West Malling, Kent, was re-built in 1966 using carefully chosen concrete blocks to blend with stone of the 11th Century buildings that surround it.

7 Concrete mass cooling
Powergen's headquarters in Coventry feature exposed concrete soffits that are cooled at night by ventilation to provide free passive cooling during the day.

8 Waving goodbye to sound
The new acoustic barrier at Gatwick Airport is 430 metres long, and protects nearby residents from the noise created by aircraft using the new standing area.

9 Invisible mending
Described as the world's oldest surviving railway bridge, Causey Arch, near Newcastle, was restored after 200 years of neglect. The work involved recreating in concrete an eroded section of the sandstone cliff supporting the arch.

Energy

Concrete's strength and versatility have earned it an important place in the production of energy, whether from oil, gas, coal, nuclear fuels, water or wind.

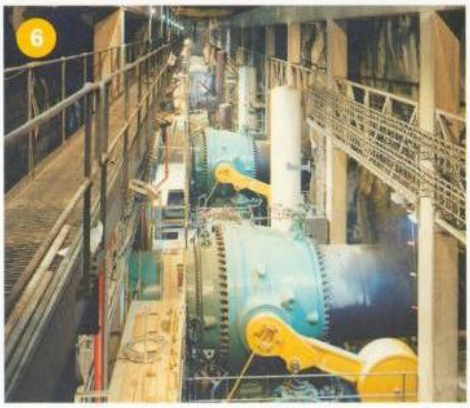
In the North Sea oil boom of the early 1970s, concrete was used to build some of the first production platforms and is still used today. These massive oil rigs are subject to harsh conditions where concrete's low maintenance needs and resistance to salt water come into their own.

The coal industry made extensive use of concrete for construction at the pit head and underground, and the tall cooling towers at electricity power stations are invariably made of concrete.

Concrete also provides the housing and power stations shielding for nuclear reactors, where its strength and impermeability to radiation help keep the environment and the site workers safe.

Some of this country's electricity is generated by massive hydropower dams, most of which are constructed of concrete because of its sheer mass, strength and resistance to water - qualities which also make it ideal for pumped storage power stations.

Looking ahead to alternative sources of power, concrete is making its mark as wind towers, both on land and off-shore and in the development of wave and tidal energy schemes.



1 Floating out to work
This massive oil platform was constructed in a dry dock on Teesside before being towed out to the Ravenspurn North Field off Scarborough where it was submerged to the seabed. Once in position the decks were added to provide production facilities and living quarters.

2 Reach for the sky
The 80 metre high winding tower (centre) at Harworth Colliery in Nottinghamshire is a surprisingly beautiful addition to the landscape, and received a Civic Trust award.

3 Curves that cool
Rows of the familiar power station cooling towers take the heat from the exhaust steam from the power turbines.

4 Whistle down the wind
The tower for this wind turbine near Stroud in the Cotswolds was constructed from concrete to reduce the reverberation and hence the noise to the surrounding inhabitants.

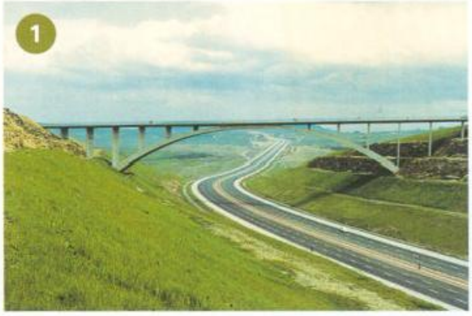
5 Power from rain
The Loch Sloy dam in the Scottish Highlands raised the level of the loch by 47 metres and doubled its length. Its catchment area was enlarged by a system of aqueducts and tunnels so that every 25 mm of rain falling can generate 1 million units of electricity.

6 Underground powerhouse
Built of concrete inside a mountain, the Dinorwic pumped storage scheme uses surplus power to pump the water to an upper reservoir. It is then released to generate electricity during periods of peak demand.

7 Nuclear protection
View of the top of one of the nuclear reactors at Heysham 2 Nuclear Power Station on the Lancashire coast. With a thin lining of steel, the concrete pressure vessel is 35 metres high and has prestressed concrete walls up to 7.5 metres thick.

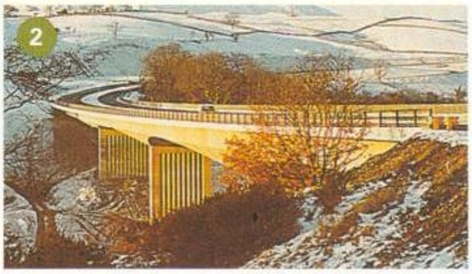
Bridges

Of the bridges built since 1945 in this country, about 70% are of concrete, which provides the strength for long, slender and elegant spans as well as the solid durability for the supports and abutments.

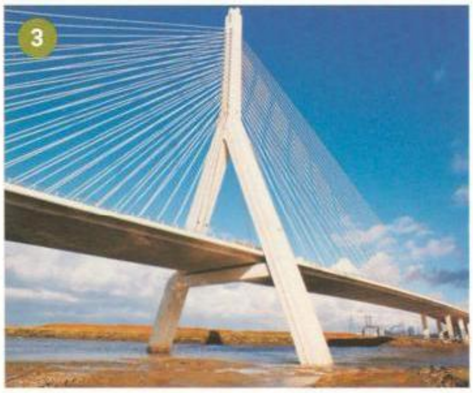


The majority of bridges built today are constructed as part of the motorway and trunk road network, providing urban flyovers and complex multi-level junctions.

A whole range of new techniques has evolved as engineering ingenuity has been stretched to its limit in order to keep up with the demands made on the country's infrastructure. Prestressing techniques play a major part in achieving longer and longer spans without the need for intermediate support.

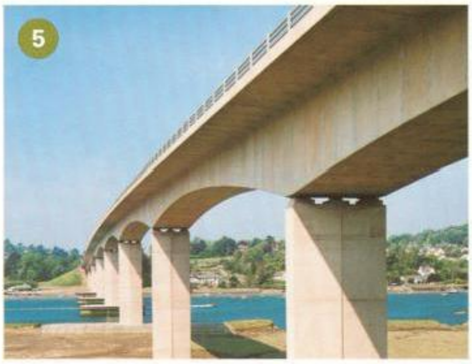


The three classic bridge shapes - arch, beam and suspension have remained little changed since man first made use of a jumble of rocks jammed across a gorge, a fallen tree trunk or some convenient hanging creepers.

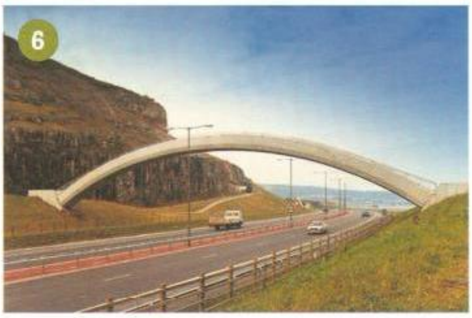


The arched concrete bridge that first caught the world's imagination was that over the Salgina Gorge in Switzerland, designed by Robert Maillart (see page 12). Today the Scammonden Bridge over the M62 in the Pennines echoes Maillart's classic lines. It has a span of 126 metres, although this form of construction can span over 400 metres.

With modern techniques, spans approaching 300 metres can be achieved with the beam method of bridge construction. The bulk of our motorway bridges are constructed as beams, but generally have much shorter spans. They are a familiar sight throughout the country, forming intricate knots at complex multi-level junctions.



The suspension bridge has evolved into the cable-stayed design, where the deck is held by cables attached to towers. The longest all-concrete span for this type of construction is 440 metres - and rising.



A recent development in bridge construction involves building them to carry roads running along steep-sided valleys. An example is to be found where the M5 runs along the Gordano Valley near Bristol.

1 Echos of the classic Maillart bridge

Scammonden Bridge crossing the M62 in the Pennines is a classic arch – a shape chosen to minimise disturbance to airflow in this exposed site that is prone to snow drifts.

2 Sweeping westwards by the Lakes

The Greta Bridge in the Lake District takes the Keswick Northern Bypass across the valley in a curve that reflects the grandeur and beauty of the countryside.

3 A for asymmetry

The asymmetric design of the River Dee Estuary Bridge leaves the navigable channel clear for shipping. The single white concrete bridge tower can support 25,000 tonnes.

4 Remote Highland beauty

The Kylesku Bridge carries the A894 across the Kylestrome in Sutherland, in the far north west of Scotland. The elegant design spans deep water in this remote and exposed site.

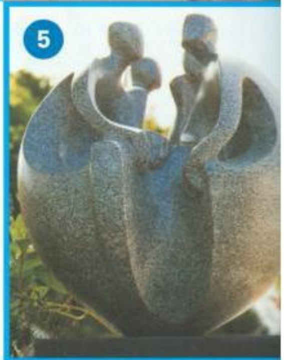
5 A bridge to sail under

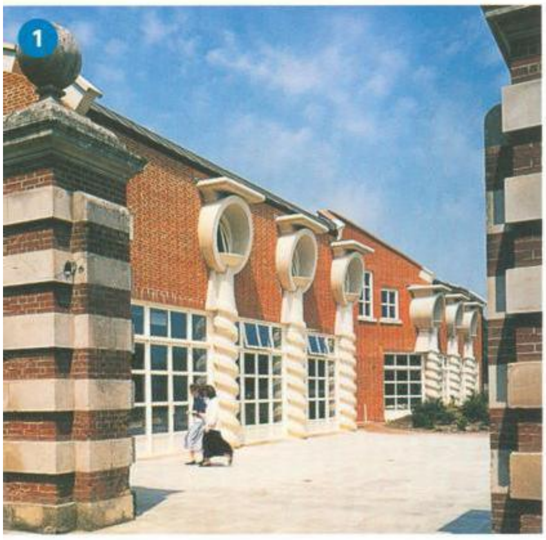
The River Torridge Bridge at Bideford in North Devon carries the A39 across the river in eight spans that curve upwards to allow a clear navigation channel up the river.

6 An arch for feet

Rounding the bend on the A55 coast road in North Wales, the motorist is greeted by the Penmaenrhos Quarry footbridge that spans the dual carriageway in a spectacular 45 metre circular arch.

Creativity and imagination



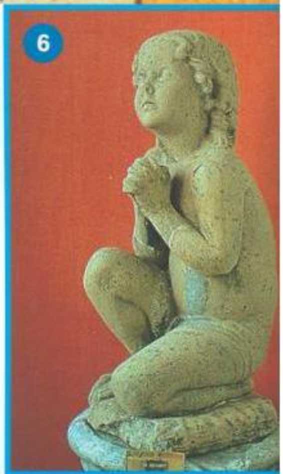


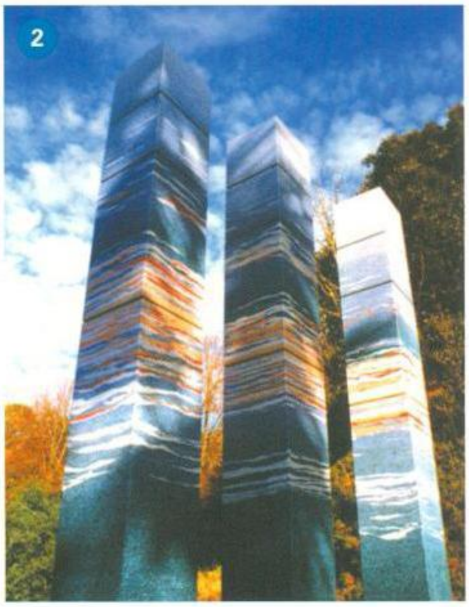
Some of the first uses for concrete in Britain were influenced by the idea that it should resemble Portland stone, but with advances in construction techniques has come the realisation that concrete can be any shape and any colour.

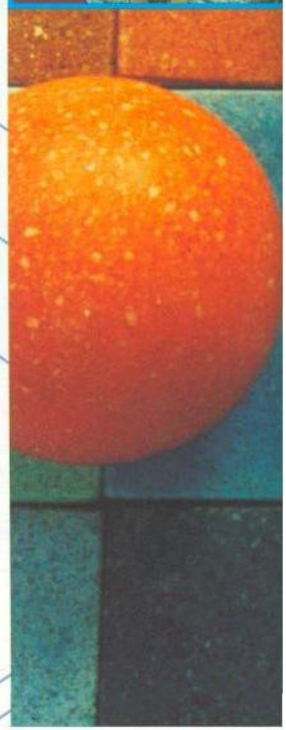
Now the only thing restricting its appearance is the imagination of the designer, as concrete can be produced by moulds of the desired shape and texture, and modern pigments and paints can impart all the colours of the rainbow.

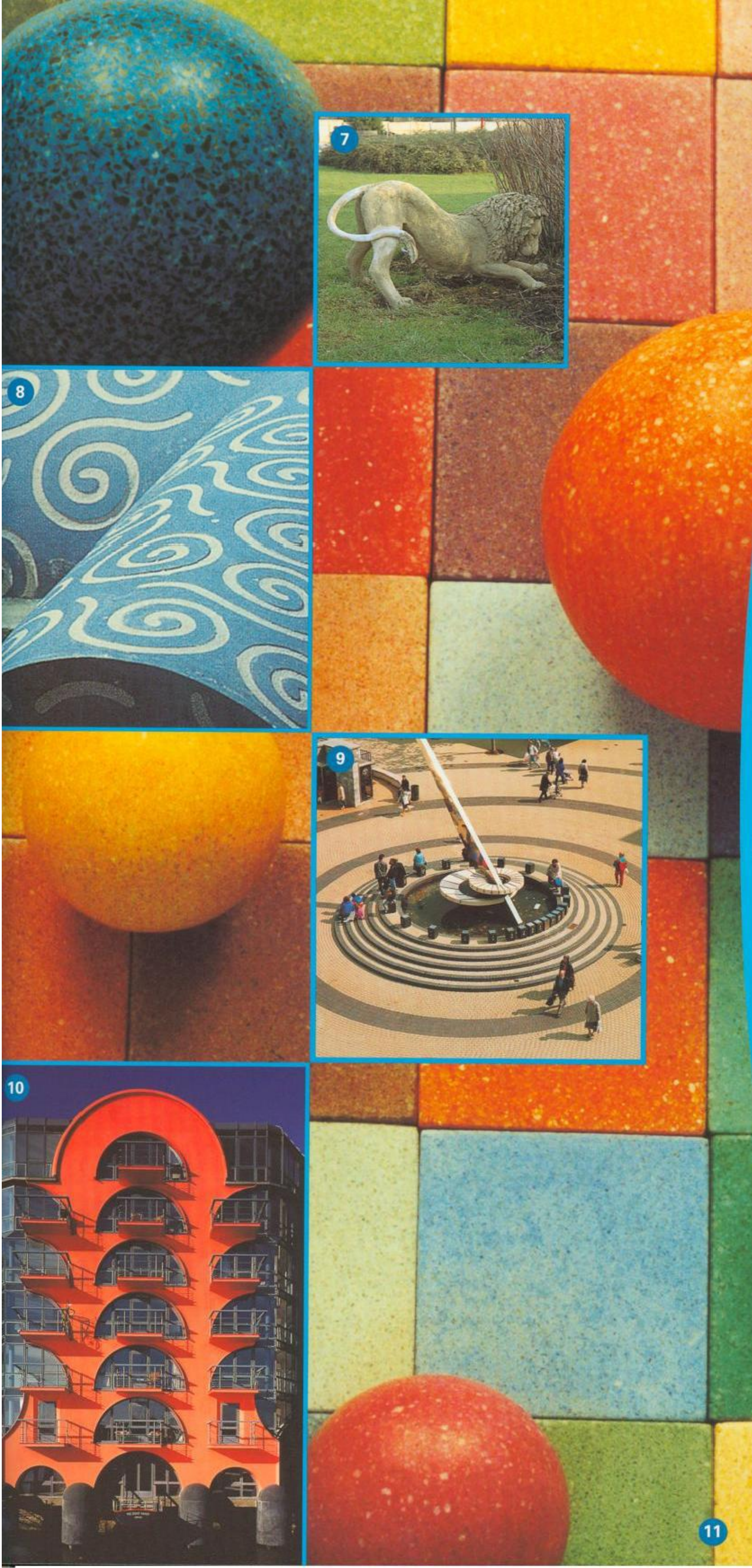
The exploitation of concrete's unique properties has resulted in some of the most exciting buildings as well as many striking and beautiful works of art.

The architectural advantages of using concrete are its strength and resistance to vandalism.









1 The twists of Shaw
Nicknamed after the original school architect, these precast concrete columns by Piers Gough add interest to the new wing at Bryanston School.

2 Atlantis
The three 7 ft high columns created by Carole Vincent stand in a private collection on the island of Jersey.

3 Forward with the past
Colourful aggregates such as brick fragments are used to produce concrete dubbed 'Blitzcrete' by the architect John Outram after the concrete made with rubble from bomb sites.

4 Starry, starry night
Fibre optics set in concrete are used by Anthony Fanshawe to create this blue and black globe with a Milky Way.

5 Colloquy
Cast in highly polished black and white concrete, this sculpture by Carole Vincent shows off concrete's mouldability.

6 Testament to a creative past
Representing the Prophet Samuel in infancy, this is thought to have been commissioned in about 1850 by James Aspdin, the elder son of the inventor of Portland cement.

7 The art of escape
With its head cast in a rubber mould, and the body made from ferro-cement, this lion by Sioban Coppinger livens up a station in Buckinghamshire.

8 Out of the blue
A feature from the Judge Institute in Cambridge by John Outram Associates resembles blue logs with a swirling pattern of clouds made by inlaying blue concrete with non-shrinking white grout.

9 The Armada Dial
The focal point of Plymouth city centre's pedestrianisation scheme, created by Carole Vincent, is the Armada Dial.

10 Spicy import
China Wharf by Piers Gough is a residential building next to warehouses on the Thames at Bermondsey. The metallic-smooth in-situ concrete façade is painted the colour of exotic spice.

11 Any colour but grey
This piece by Carole Vincent illustrates the range of colours that can be imparted to concrete.

Looking ahead

The way forward for concrete construction will be largely influenced by the need to conserve the earth's resources, be they materials, land,or energy.

The need for more and more office space in our already overcrowded cities will lead to more immensely tall office blocks such as the Petronas Towers in Kuala Lumpur in Malaysia. Built with concrete foundations, cores and columns, at 88 storeys or 452 metres high they are currently the world's tallest buildings. The proposed Grollo Tower in Melbourne will be taller still at 565 metres, with 120 storeys.

Edifices such as these consume enormous quantities of energy to provide air conditioning and access via lifts. Where there is more space, three- to four-storey blocks such as the new British Airways headquarters are a less resource-hungry solution. This has been constructed on a site reclaimed from its previous use first as a gravel pit, and then for waste disposal, and provides a good example of re-use of another scarce resource - land for building.

The growing concern about the lack of space above ground in our towns and cities will increasingly result in development taking place below ground for shopping, parking, recreation and transport, as well as for utilities such as power generation and water treatment. With its strength and durability, concrete will be the prime construction material used for these developments. London's Hyde Park already conceals underground parking beneath its greenery and nearby, below Park Lane, is a three-storey underground car park.

Efforts to reduce the use of energy have resulted in the development of passive cooling techniques, where the mass of concrete is used as a reservoir of 'coolth' that can be used when required (see page 26). Natural ventilation is another step in this direction that is already in use.

Sustainable development involves meeting present needs without compromising the ability of future generations to meet theirs. This is likely to lead to the re-use of current buildings, rather than tearing them down to start again. Refurbishing or upgrading existing buildings is one route to their re-use, another is to design with a probable change of use in mind.

The quest for sustainability means realising that the price of a building is far more than its initial construction cost. Whole-life costing also includes the cost of energy needed to run the building, its maintenance and repair, and its eventual demolition or adaptation for another use.
This means that its design has to be integrated with its method of construction, maintenance and upgrading.

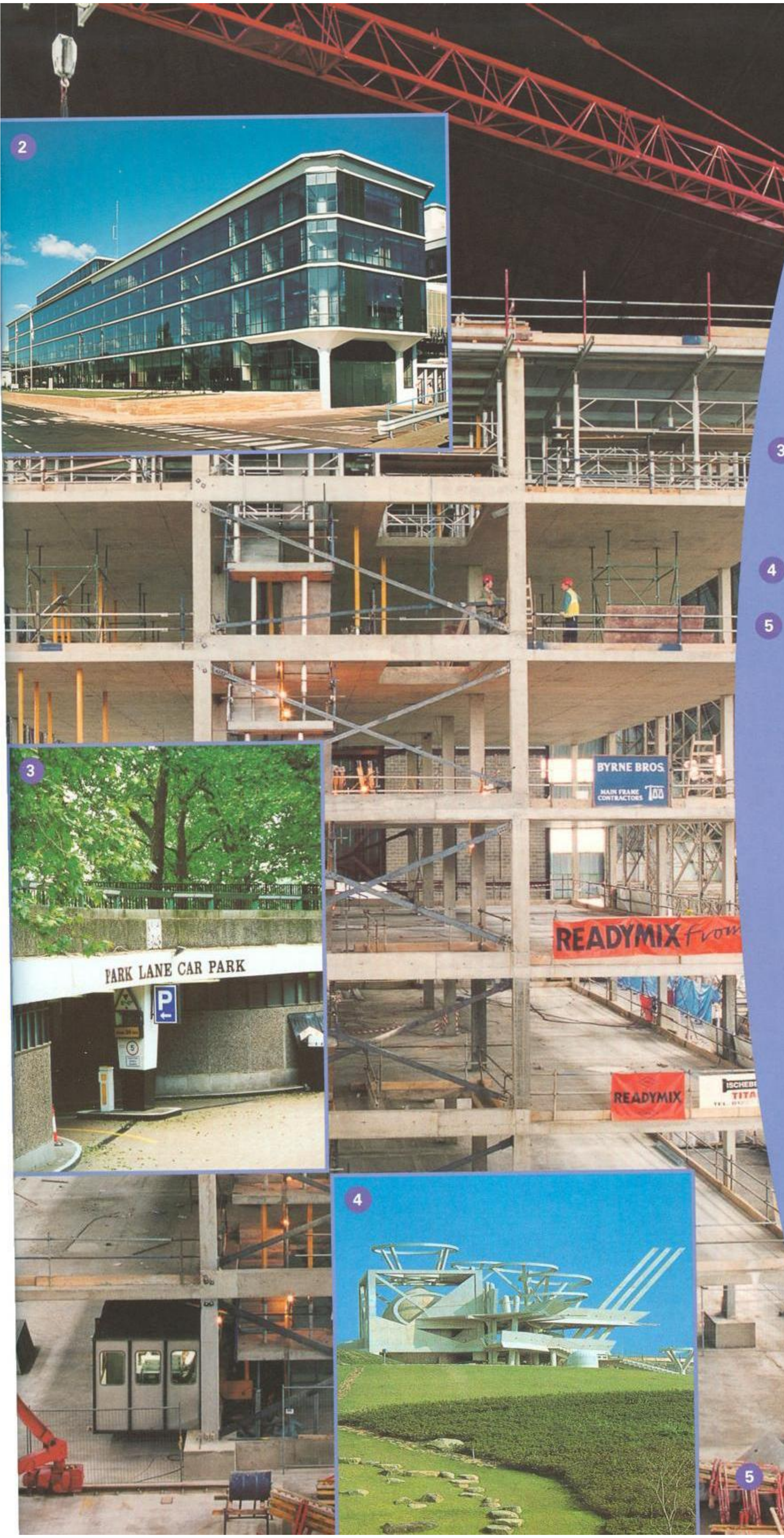
Skilled site labour is another resource that is likely to run short. Innovative construction techniques can help overcome this. Self-compacting concrete will be easier to place correctly, and unmanned equipment could be used to make concrete floors.

Transferring some of the construction process to a controlled operation in a factory is another way of coping with a lack of skilled labour. For example, whole bathroom 'pods' can be assembled off-site, even down to the installation of plumbing and tiling, and then slotted into place on site.

Running alongside all these concepts will be the development of concrete as a material. Continued advances in cement and concrete production, alternative reinforcing materials and the use of computer-aided design will ensure that concrete remains the major construction material.

Complementing this development in materials will be the adoption of construction techniques that will cut out waste and reduce the time taken on site, so shortening the period before a building or structure can be brought into use and begin to earn its keep.

Construction techniques and products are being evaluated on a seven-storey concrete framed test building at Cardington in a unique project involving many companies and organisations from the construction industry.



1 Ever upwards in congested cities

The Petronas Towers in Kuala Lumpur reflect man's desire to build the tallest.

2 Refurbishment - facelift for a factory

The Boots' factory in Nottingham, built in 1932, was refurbished in the early 1990s. Modern laboratory and office facilities were provided to meet the company's business needs without affecting the architectural style of this listed building.

3 Concealed parking

Underneath Speakers' Corner in Hyde Park, London, is parking for 1000 cars, while above it the welcome green in the city remains unchanged.

4 Reaching for the stars

Japan's Tanama City Observatory.

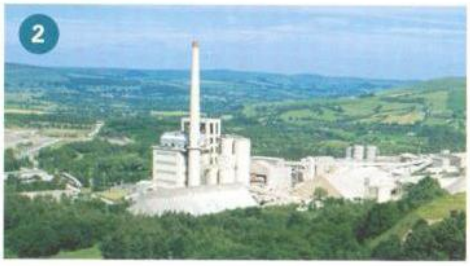
5 Full-scale testing

This seven-storey concrete building was built specifically to investigate efficient ways of building and improving the construction process, and will include an investigation into the effects of fire.

Cement - its manufacture and chemistry

The first Portland cement was made by burning together batches of a mixture of chalk and clay in a bottle kiln. These formed a fused clinker that was ground to a fine powder. The same principles are applied today except that either chalk or limestone may be used, together with clay or shale. The process has improved so that it is continuous, using a rotary kiln to sinter a carefully controlled mix of materials at higher temperatures.

Caring for the environment
The raw materials used for Portland cement are obtained by quarrying and great care is taken to avoid causing nuisance to the local area and its inhabitants. The quarrying techniques used reduce waste, and the movement of lorries is minimised by siting cement works adjacent to the quarries.



When a quarry is exhausted, it may be either reinstated to farmland, or turned into a site of Special Scientific Interest where wildlife can flourish. Or it may be given new life, perhaps as a water sports and recreation centre or a shopping complex or building development. Sometimes disused quarries become landfill sites before final reinstatement as farmland, so helping to solve one of today's major problems - waste disposal.

Cement making is a highly sophisticated industrial process that operates under very strict environmental controls governing the nature and amount of the waste material given out to the air, water and land, although releases to the last two are inherently low.

The extremely high operating temperatures reached in cement kilns mean that they can safely burn fuels made from waste products such as used car tyres and industrial solvents. This helps conserve fossil fuels by recovering energy from waste whilst minimising disposal to landfill.

Cement chemistry
The calcareous materials used to make the cement (the chalk or limestone) provide calcium. This reacts with the silica, alumina and iron in the argillaceous materials (the shale or clay) to form a clinker of calcium silicates, calcium aluminate and calcium aluminoferrite. The cement clinker is finely ground with a small amount of gyspum to create Portland cement.

The addition of water to cement causes it to set and harden. This is due to a chemical reaction between the water and the calcium silicates that causes cement hydrates to grow and interlock with one another. The process is called hydration and can continue for a long time, increasing the strength of the concrete over many months.

Cement has been manufactured to conform to British Standards since 1904. Now that the countries of Europe have formed a single market, a European standard is being finalised by the members of the European Union.

Nowadays, cements are not necessarily composed of Portland cement only; they may also contain other materials such as ground granulated blastfurnace slag, a by-product of the production of iron, or pulverized-fuel ash, a by-product of burning coal in power stations.

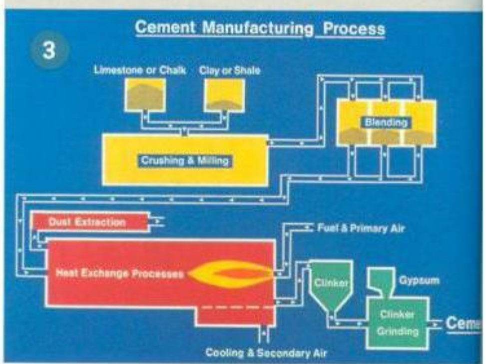
Transporting cement
Freshly made Portland cement obviously has to be kept dry and is transported in bulk in airtight containers either by rail or by road. For the small building site it is delivered in strong paper sacks lined with polythene. Recently the weight of these sacks has been reduced to 25 kg, so reducing the risk of back injury for site workers.

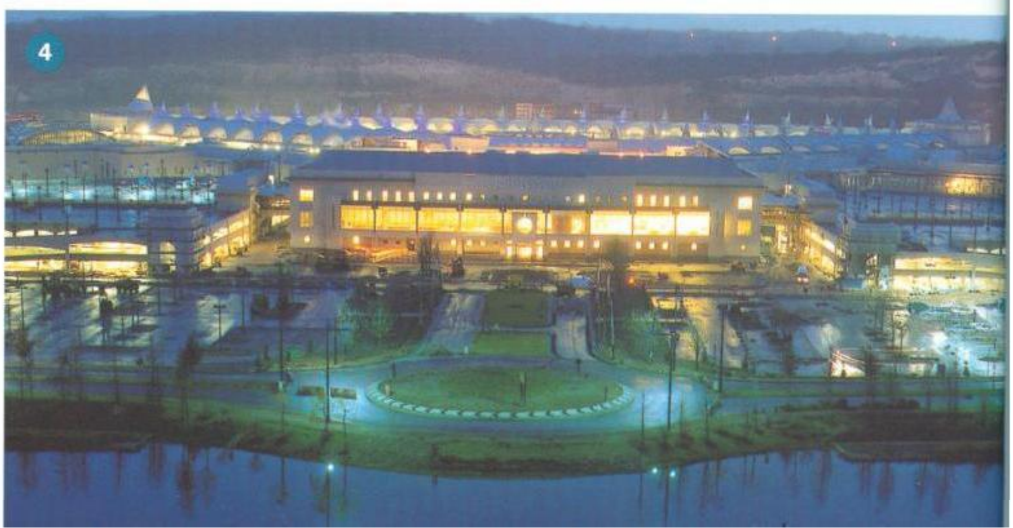
1 Quarrying the raw materials
This limestone quarry at Buxton in Derbyshire at one time had the largest working quarry face in Europe.

2 Cement works
This cement works in the Peak District National Park is sited close to quarries for both limestone and shale, so reducing the amount of lorry movement in the surrounding area. The landscaping of the site that began in 1943 was one of the first for a UK industrial site, and was undertaken by Sir Geoffrey Jellicoe, a leading landscape architect.

3 The cement-making process
Raw materials are delivered in bulk, crushed and fed into the kiln, where they are burnt to produce clinker, which is then ground to a fine powder.

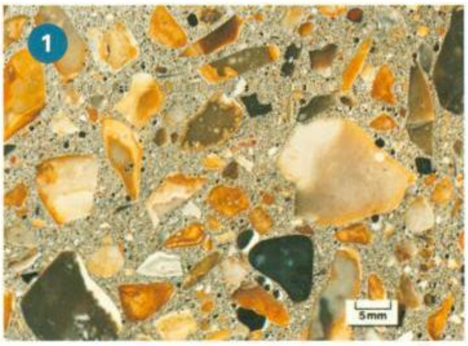
4 Making good use of a former quarry
Bluewater, a new retail and leisure complex in north Kent, is built within a former chalk quarry owned by a major cement maker. At the time of construction it was the largest such complex in Europe, and provides out-of-town shopping, cinema and sports facilities for the inhabitants of a large part of the South East.





The making of concrete

Concrete making has moved on from its earliest beginnings some 9000 years ago but the principle is still broadly the same - pieces of an inert hard material, such as gravel or crushed rock, together with sand to fill the gaps, are mixed with a paste of cement and water. This hardens over time to bind it all together, producing an extremely durable solid mass.



Aggregates

About three-quarters by volume of concrete consists of fine and coarse aggregate - sand, gravel and crushed rock - obtained from pits, quarries and the seabed. Great care is taken to minimise the environmental impact of the quarrying activities, and to restore the workings to countryside or transform them into something useful such as a water sports facility.

One quarry that has a minimal visual impact is Glensanda near the island of Mull on the west coast of Scotland, where a remote mountain is being mined for its granite. Here the rock from the top of the mountain is dropped down a 'glory' hole in its centre and is then conveyed along a tunnel to the shore for processing and loading onto bulk carriers.

In addition to the traditional quarried aggregates are artificial types such as sintered pulverized fuel ash (a by-product of burning coal in power stations) and expanded shale, both of which make a lightweight aggregate where the weight of the concrete is critical. To reduce the environmental impact of concrete production, the crushed remains of demolished concrete buildings will be increasingly used as part of the aggregate in concrete for new buildings (see page 26).

Making concrete

Fresh concrete is flowable and gains its final shape from the use of a mould, known as formwork. This can be constructed on site from timber or steel and is removed when the concrete is sufficiently hard to retain its shape and take some load.

Concrete can also be delivered to site as precast units that have been made in a factory. Here the moulds are precision-made, usually of steel, and can incorporate intricate patterns.

Concrete mixes are described in terms of the proportions of their constituent materials. The mix is specified according to the required strength, appearance, durability (ability to withstand a harsh environment) and workability (ease of placing). By altering the proportions of aggregates, cement and water, changes can be made to the properties of the fresh and hardened concrete.

Special properties can be imparted to the fresh concrete by the use of admixtures. For instance, accelerators speed up the hardening process, while retarders slow it down. Plasticisers make the concrete flow well - around steel reinforcement for example - without adding any extra water. Air-entraining admixtures can be used to introduce small bubbles that help the hardened concrete resist freezing and thawing.

When making concrete, it is important that the specification is carefully followed as, for instance, too much water will result in a porous, weaker and less durable concrete. It is also important to compact it carefully, ensuring that the air voids are expelled and that the concrete completely fills the formwork.

After placing concrete, it should be cured, that is, kept moist long enough for the cement hydration process to develop so that the concrete gains its required strength.

1 Concrete
Cross section of concrete showing the coarse aggregates of various sizes and sand particles bound together by the grey cement matrix.

2 Concrete mixer
For smaller projects, concrete is mixed on site.

3 Ready-mixed concrete plant
The controls at a ready-mixed concrete plant ensure that an accurate mix is produced.

4 Ready-mixed concrete
For larger projects concrete is delivered to the construction site already mixed. Here a truck mixer collects a consignment of ready-mixed concrete.

The making of concrete

Continued from page 35

Concrete can be made on site, with the cement, water, sand and coarse aggregates being mixed either by using a concrete mixer or by shovel for very small quantities. Nowadays, however, most concrete is supplied to site by a ready-mixed concrete truck from a plant where it has been made accurately to precise specifications.

Types of concrete

By changing the type of aggregate, concrete can be made so light that it can float, or so heavy that it is almost twice its usual density. It can be made impermeable for use in dams or porous to let the water percolate through as in filter-beds at sewage treatment plants.

The surface of concrete can be as smooth as glass or the aggregate can be exposed to make a decorative textured finish. Pigments can be added to create a choice of colours.

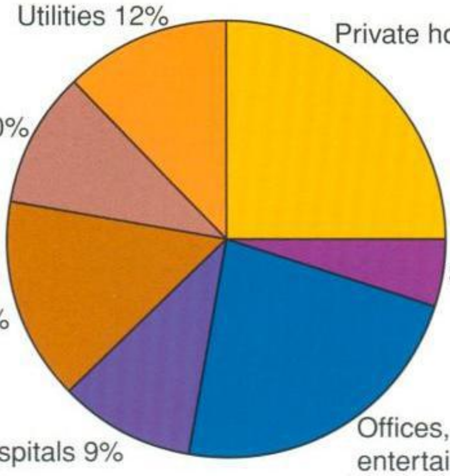
Foamed concrete is made by mixing a foaming agent with mortar. The resulting material is very free-flowing and is ideal for filling trenches in roads, with the added advantage that it can be easily removed for later access. In contrast, high-strength concrete is used to provide the necessary strength and durability for North Sea oil rigs.

Thus, by the correct choice of materials and construction techniques, there is almost no application for which concrete cannot be used.

1 At the site

Concrete is pumped to where it is needed, and vibrated to compact it thoroughly.

Where concrete is used



The British Cement Association

The British Cement Association is a focus for the concrete industry, and its mission is to promote the greater and better use of cement and concrete through its role as a:

- trade association
- scientific research association
- industrial training organisation for cement
- provider of concrete information services
- market development partner with the concrete industry
- research partner with Government, industry and universities

BCA Member Companies

The four major manufacturers of cement in the UK are:

Blue Circle Industries plc
UK Cement
84 Eccleston Square
London SW1V 1PX
Tel: 0171 828 3456
Fax: 0171 245 8229

Castle Cement Ltd
Park Square
3160 Solihull Parkway
Birmingham Business Park
Birmingham B37 7YN
Tel: 0121 779 7771
Fax: 0121 779 7609

Rugby Cement
Crown House
Rugby
Warwickshire CV21 2DT
Tel: 01788 542 111
Fax: 01788 540 166

Buxton Lime Industries Ltd
Tunstead Quarry
Wormhill
Buxton
Derbyshire SK17 8TG
Tel: 01298 768 555
Fax: 01298 768 556

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Page	14	Coventry Cathedral	Ove Arup and Partners
Page	15	University of East Anglia	Frank Hawes
Page	15	Sydney Opera House	Bill Stotesbury
Page	16	Swimming pool, Oxfordshire	Architects Design Partnership
Page	17	Concrete drive	PICS Ltd/Paverprint
Page	18	Traffic barrier	Marksman International
Page	19	Station	Roger Eastell
Page	19	North Greenwich Underground Station	QA Photos/Jubilee Line Extension
Page	20	Ealing Hospital Maternity Unit	HML Architects
Page	21	Duxford Air Museum	Nigel Young
Page	21	Wimbledon	Building Design Partnership
Page	22	River retaining wall	MMG Civil Engineering Systems Ltd
Page	22	Concrete yacht	Robin Gates
Page	23	London Ring Main	AMEC Civil Engineering Ltd
Page	25	Vauxhall Cross	Roger Eastell
Page	26	St Stephen Wallbrook	Thomas Photos, Oxford
Page	27	St Mary's Abbey	Elain Harwood
Page	28	Ravenspurn oil rig	Ove Arup and Partners
Page	28	Dinorwic Power Station	First Hydro Company
Page	29	Scammonden bridge	Pell Frischmann Consultants Ltd
Page	29	River Dee Estuary Bridge	Roger Brown
Page	30	Twists of Shaw	Jo Reid & John Peck/CZWG Architects
Page	30	Atlantis	Gareth Syvret
Page	30	Starry, starry night	Martin Thomas
Page	30	Colloquy	Karen Partridge
Page	31	China Wharf	Jo Reid & John Peck/CZWG Architects
Page	31	The art of escape	Roger Eastell
Page	31	Any colour but grey	John Beswick
Page	32	Petronas Towers	Laurence Hill
Page	33	Tanama City Observatory	Takasaki Masaharu
Page	34	Bluewater	QA Photos Ltd

Also many photographs used on pages to 16 to 31 that were taken by Trevor Jones

Further reading

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