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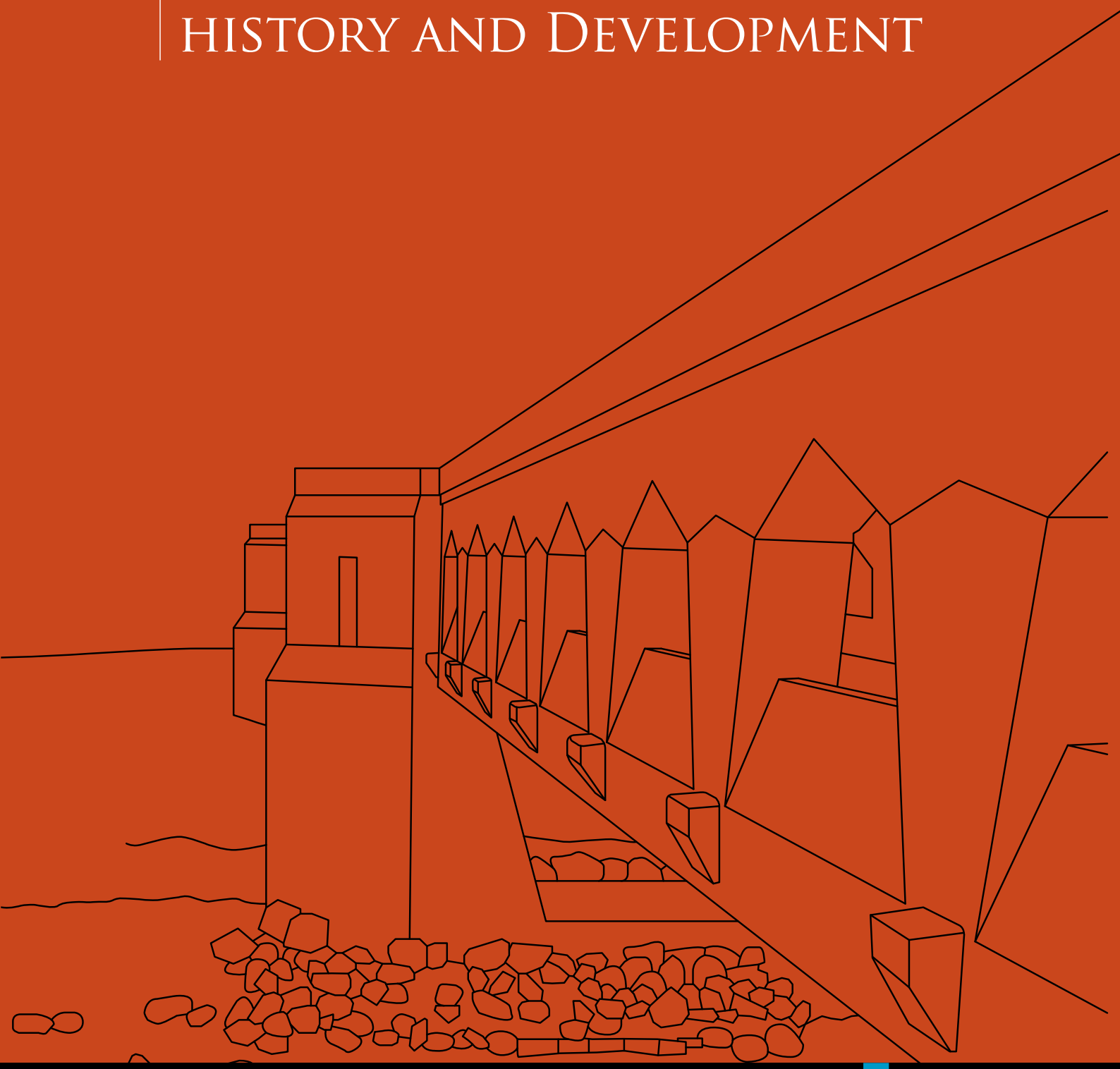
Short Guide

Historic Concrete in Scotland Part 1: history and Development



Historic Scotland
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ISBN 978-1-84917-119-9

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Published by Historic Scotland, March 2013

Historic Scotland, Longmore House, Salisbury Place, Edinburgh, EH9 1SH

Acknowledgements

The author acknowledges the encouragement, support and advice received from the following persons: Ingval Maxwell OBE for reviewing the document and ensuring that conservation issues of historic concrete are appropriately addressed; John Duncan, former Conservation Officer, Highland Council and Andrew Wright OBE for identifying some of the historic concrete structures in Scotland.

Thanks are also due to the staff of Ardtornish Estate in Morvern for showing the author some of the many historic concrete buildings on the estate. The manuscript was edited by Roger Curtis, Carsten Hermann and Emily Horne of Historic Scotland.

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Contents

1. Introduction

A significant point that has emerged from this and other studies is that concrete has been significantly utilised as a building material in Scotland over the last two centuries. It was not only restricted to constructing large scale engineered structures, but has in fact been used for a wide range of buildings including agricultural, domestic, maritime and military. In some areas, especially the northeast of Scotland, it can qualify as a vernacular material where it was used at all levels of the community. Concrete was used in farm buildings, cottages, rail and water infrastructure as well as in a formal architectural context as seen in several large country houses of the late 19th century.

This Short Guide, the first of three on the subject of historic concrete structures in Scotland, sets out the early development of the material and how it has been used since the mid 19th century. This and the following volumes do not seek to be the sum total of knowledge on the subject, rather an overview for those new to aspects of building conservation. More detailed material is available, especially in the well established area of concrete repair, where the role of the structural engineer will play an important part. References to further sources of information are provided in this and the accompanying volumes.

The durability of this relatively new material has been proven, with the proviso as with all structures, that the structure is well maintained. Above all, the dispersal of water must be effective if mass or reinforced concrete structures are to survive.

The Appendix of this guide contains a table of concrete structures found in Scotland. The majority of these examples are protected through listing. The list is not exhaustive and other buildings may be added in due course. However, by understanding the extent and scope of the resource, designers, practitioners and others in the sector can place their projects in a wider context.

The primary focus of this Short Guide and the accompanying publications is on the historical development and use of concrete (mass, precast and reinforced) in Scotland between 1840 and 1945, and the background to its conservation and repair highlighting indicative examples and techniques. This is a period when concrete as a building material developed from an innovative yet poorly understood material to what is described as modern concrete with design codes of practice introduced in the 20th century.

This document, as part one of three, seeks to establish an understanding and context for concrete as a building material in order to provide a basis for outlining principles of its conservation and repair (parts two and three). It focuses on explaining the historical development of concrete and its characteristics, the variation of types and its uses within Scotland's built environment.

2. History and background

The use of concrete as a construction material can be traced back to ancient times, with well documented examples of the Romans making extensive use of hydraulic cement concrete, a mixture of lime putty and pozzolana. This material should not be confused with Roman cement, a quite different material developed by James Parker in the 1780s. Roman concrete was used mainly as a filling within masonry and brick walls. As a building material, however, concrete was lost for some time until a revival during the Middle Ages. At this time, and until the mid-to-late 19th century, concrete was made using lime. It was not until towards the end of the century that modern concrete, which used Portland cement instead of lime, began to be used. Patented by Joseph Aspdin in 1824, it was firstly used mainly as mass concrete for floors and engineering structures such as foundations, harbours (Fig 1) and bridges (Figs 2 and 3), where its inherent compressive strength and setting capability could be used to great advantage. Throughout the late 19th century concrete developed into precast elements and reinforced concrete, which expanded its use as a building and structural material (Figs 4 and 5).

In broad terms the essential characteristics of early concrete are similar to modern concrete in that both are a composite of a cementing material (natural cement in the form of hydraulic lime or Portland cement), fine aggregate, coarse aggregate and water. A form of what could be described as concrete can be found in medieval walls that have a rubble and lime mortar filled core. The lime used as the binder was generally a non-hydraulic lime which hardened only on exposure to carbon dioxide. As these walls can be several metres thick it could take centuries for air to penetrate to the centre of the wall to carbonate (harden) the lime. Natural Hydraulic Lime (NHL), due to the fact that it contains clay, has the ability to harden under water and thus harden in the absence of air. During the latter part of the 19th century there was a gradual replacement of lime by Portland cement as the preferred binding agent until the first decade of the 20th century, when most concrete structures used this material. However, lime still continued to be used in combination with Portland cement to provide better workability to mortars and plasters.

Fig 1 Dundee Harbour dating from 1833. © Historic Scotland

Fig 2 Killin rail viaduct over the River Dochart (1885-86) is the second oldest mass concrete viaduct in Britain after the Falls of Cruachan. © Historic Scotland

Fig 3 Forth Bridge (1883-90). Britain's first major steel structure is supported upon concrete and masonry piers. © Historic Scotland

The major weakness of concrete as a structural material is its low tensile strength. This led to the development of reinforced concrete, which produced the very versatile structural material we are familiar with today. A number of patented systems of reinforcement were introduced, particularly in France by Hennebique and Coignet in the 1880s and 1890s. Large numbers of such structures were built in Britain between 1900 and 1919, including in Scotland where proprietary systems (many of which were the Hennebique system) were adopted for a range of structures such as buildings (Figs 6 and 7), bridges, viaducts, harbours, reservoirs and militaria. At this time, a correct theoretical understanding was developed of the use of reinforcement to increase strength in areas of concrete that perform under tensile stress.

When dealing with early concrete structures that incorporate 'modern' or Portland cement, it should be recognised that modern concrete has undergone much research and development since its introduction in the 1800s. Compared with the concrete of today that uses finely ground high strength cements and high quality well graded sands and aggregates, the early concretes were made with natural hydraulic lime and early Portland cement and have significantly less compressive strength and greater permeability. Also, the lack of knowledge and understanding at the time of the properties and performance of the constituent materials and how to prepare, place and cure the concrete, has had an impact on its durability. Therefore, before any work is done on historic concrete structures it is necessary to understand the nature of the material and not to equate this with modern concrete structures. It should be noted that hydraulic lime was used in the production of these early concretes whereas non-hydraulic lime was used for mortars, plasters and lime washes. However, the specification for the manufacture of Portland cement underwent a gradual process of refinement until c.1920, at which point cement was approximately similar to that which is used today.

Fig 4 St Aloysius Church, 23, 25 Rose Street, Glasgow (1908-10). A neo-baroque, Jesuit church with concrete roofs and cupolas. The form of concrete construction for the roof is thought to be reinforced.

Fig 5 Institute Street, Portsoy, Aberdeenshire (1884). An early example of the use of painted precast concrete for dressings, skews and chimneystacks.

Summary:

- Prior to the mid-19th century concrete was made with lime and predominately used as a filling within brick and masonry walls
- Portland cement was first used to make concrete in the 1820s and gradually replaced lime as a binding agent during the latter part of the 19th century
- Early concrete was first used in mass mainly for engineered structures such as foundations, harbours and bridges
- Reinforced concrete and precast elements developed in the late 19th century, broadening the use of concrete as a building material
- A number of patented reinforcement systems were introduced in the early 20th century, with the Hennebique being commonly used in Scotland
- Early and modern concretes are similar in that both are a composite of a binding agent (hydraulic lime or Portland cement) fine aggregate, coarse aggregate and water
- It is important not to equate early concretes, even those using Portland cement, with modern concrete as the material has undergone significant development, particularly during the 20th century


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Fig 6 Sentinel Works, 61 Jessie Street, Glasgow (1903-4). An early ferro-concrete construction built on the Hennebique system. © Daniel Dubowitz

Fig 7 Watson's Bond, Seagate, Dundee (1907). Reinforced concrete frame using the Hennebique system and brick cladding. © Douglas MacKenzie


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3. Development of concrete buildings and structures in Scotland

Stone is the traditional, and generally regarded as the principal, building material in Scotland. Each community would utilise this readily available resource for the construction of buildings and engineering works, including bridges, harbours, dams, lighthouses. In addition, the use of earth (clay) for wall construction was common in areas of Scotland such as in the Carse of Gowrie, Moray (especially around the mouth of the Spey) and in south west Scotland around Gretna (Orr, 1985). It is in these areas that the early use of mass concrete can be found; one of the earliest recorded examples being the use of mass concrete for the foundations of Kinfauns Castle in 1825 (Walker and McGregor, 1996). There is a seeming relationship between the use of mass concrete walling and clay wall construction. Clay walls, with or without added gravel or other aggregates, were sometimes constructed using timber boards to form shuttering into which the clay was rammed in layers, otherwise known as pisé. At times, a masonry facing was added to the completed wall or built as a lining within shuttering. It was therefore only a short step to substitute the rammed earth (clay) with concrete incorporating a hydraulic-lime binder: the basic method being similar to rammed-earth construction. Wright (2012) reports that 'Scotland's mass concrete buildings are not unknown throughout the counties of the east coast from Dundee northwards and particularly in those regions where there had been an established 'clay and bool' tradition of construction, which adapted readily to the technique'.

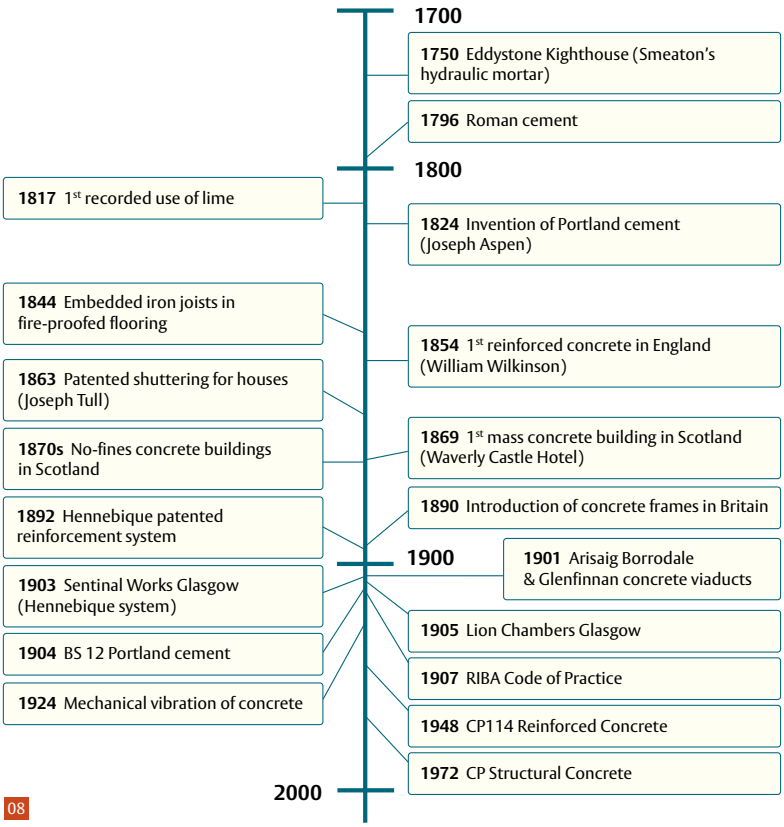

Fig 8 Significant events relevant to the development of concrete in Scotland.

Fig 9 Section through a late 19th century mass concrete wall, formed using shuttering into which a concrete mix has been poured and a cement render applied to the external face (right-hand side). The short vertical 'lifts' of the pour can be discerned. The ironwork is a later addition and not part of the structure.

Fig 10 Tugnet Ice House, Bellie, Moray (1830). Three round headed gable elevations, constructed in rubble-built stone. The long east elevation with louvered vents (ice chuts) is an early example of shuttered mass concrete.

Fig 11 Rear view of Tivoli Theatre, Aberdeen (1872). Early use of mass concrete to rear and party walls with a cement render and paint finish.

Before 1904 there were many different types of cement on the market, each with different 'recipes' and as many different client specifications (Somerville, 2001). The Engineering Standards Committee of the Institute of Civil Engineers (ICE) published British Standards (BS) 12, a specification for Portland cement, in 1904. The introduction of BS 12 led to the publication by the Royal Institute of British Architects (RIBA) in 1907 of what could be regarded as the first Code of Practice for reinforced concrete. Figure 8 shows a timeline detailing the principle events concerning the development of historic concrete.

3.1 Mass concrete

Mass concrete is cast in-situ with no reinforcement and formed using shuttering (Fig 9). Its use as a construction material in Scotland can be seen as early as 1830 (Fig 10) and numerous examples of its use between 1850 and 1900 can be found. It was used on a variety of scales, for example the Category A listed Tivoli Theatre in Aberdeen (Fig 11), Category A listed Beachtower in Dundee (Fig 12) and Category B listed terrace of Kings Crescent in Aberdeen (Fig 13). In addition, many other types of buildings can be found throughout the country including cottages, agricultural buildings, tenement buildings, hotels, churches, harbours, bridges and lighthouses.

Mass concrete was used mainly as a walling material for buildings and where mass was required for gravity such as in dams, reservoirs, retaining walls and maritime structures. It became a relatively popular material in the Highlands perhaps due to difficulties in the supply of suitable stone, the adverse climate in relation to lime working, lack of availability of imported materials and the advantage of speed of building with mass concrete. It was extensively adopted by some of the larger landowners for buildings on their estates, for example at Ardtornish Estate in Morvern, Argyll during the 1870s. The extension of the railway system into the west Highlands saw the use of mass concrete for the construction of viaducts and bridges. The Falls of Cruachan viaduct, built in 1880, was the first railway viaduct in Britain with mass concrete arches.

Glenfinnan viaduct, built in 1901, with 21 arches is the longest concrete viaduct in Scotland (Fig 14) and Category A listed. The associated viaduct at Arisaig also built in 1901 was the longest single-span mass concrete bridge in the world at the time of construction.

Fig 12 Beachtower, 6 Ralston Road, West Ferry, Dundee (1875). An early example of shuttered mass concrete used on a large domestic scale.

Fig 13 Early mass concrete houses with rendered and painted finish, Kings Crescent, Aberdeen (1875).

Mass concrete:

- Cast in-situ with shuttering and no internal reinforcement
- Mainly used for walling
- Mix typically contains fine aggregates
- Used frequently between 1850 -1900 for many types of buildings and structures

3.2 No fines concrete

In the same way as mass concrete, no fines concrete was shuttered with no reinforcement, however the aggregate used was very coarse with virtually no sand (hence 'no fines'). This resulted in extensive voids or air gaps in the matrix and produced a different density to mass concrete (Fig 15). Whether the use of concrete with a limited fine aggregate content was a deliberate design choice or simply a reflection of material availability is unclear. However, the large proportion of voids does reduce the absorption of water limiting rainwater penetration. A number of domestic buildings were constructed using 'no fines' concrete in Scotland during the late 19th century, including the well known tenement development at Court Street, Dundee (1874-5) (Fig 16) and many buildings on the Ardtornish Estate, Morvern constructed during the 1890s.

Ardtornish Estate was a pioneer in the use of no fines concrete in Scotland. A large number of buildings, ranging from the mansion house (Fig 17) to simple cottages and farm buildings, were designed by Samuel Barham who was employed by the Estate between c 1875-90 and used an early form of cement for both concrete mixes and renders. Many of the houses on Ardtornish Estate, including the Estate Manager's (Fig 18), are covered with a cement render and painted finish as a result of the relatively rough surface finish to shuttered concrete, which occurred even with care taken and well formed shuttering.


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Fig 14 Part-view of the mass concrete Glenfinnan railway viaduct in the west Highlands.

Fig 15 'No fines' concrete on Ardtornish Estate, Morvern (c.1880). Note the aggregate here is simply beach or river shingle.

Fig 16 Court Street, Dundee, 'The Connies', (1874-5). An innovative early use of no fines mass concrete with a buff textured paint finish on cement render.

Fig 17 Ardtornish Mansion, Ardtornish Estate, (1884-91). Mainly constructed of no fines concrete with sandstone facing on the south and west elevations.

Fig 18 Ardtornish Estate Manager's house (1875). Shuttered concrete with a cement render and painted finish.

Some of the Ardtornish buildings are in good condition, but others display cracking associated with concrete construction. In some cases cracks have been caused by shrinkage due to external factors. In others, the serious corrosion of wrought iron used extensively for lintels over openings and built in as supports for floors has caused the surrounding concrete to crack and disintegrate.

No fines concrete:
- Cast using shuttering and no reinforcement
- Mix consisting of coarse aggregates
- Rough density with large proportion of voids
- Used to construct many domestic buildings during the late 19th century
- Mainly used as walling material

3.3 Precast concrete

Although not generally recognised, there are many examples of precast concrete being used in building construction as early as the mid 19th century, both as masonry blocks or as a substitute for natural stone for dressings or margins to openings, ornamental features and copes to chimneys and walls. The use of precast concrete components in buildings in fact pre-dates most other uses of concrete (Hurst, 2001). Precast concrete blocks were used extensively, for example, in the coastal towns of what was formerly Banffshire. It was a common custom to paint the concrete to emulate ashlar or stone quoins and other dressings within masonry elevations. A good example of this practice is at Winston House, Banff (Fig 19), where painted precast concrete acts as a substitute for stone dressings, margins and corniced chimney stacks within the squared rubble front elevation. It is likely that, as it is painted, the use of precast concrete in this context commonly goes undetected and unrecorded.

Precast elements have proven to be durable and long lasting even in exposed maritime locations where arrases and other details survive in good condition (Fig 20).

Fig 19 Winston House in Banff (1897). Painted precast concrete has been used to emulate stone quoins, dressings, margins and corniced chimney stacks within the squared rubble front elevation.

Fig 20 A late 19th century house in Banff. Unpainted precast concrete has been used for dressings, quoins, skews and corbels within rubble and ashlar elevations.


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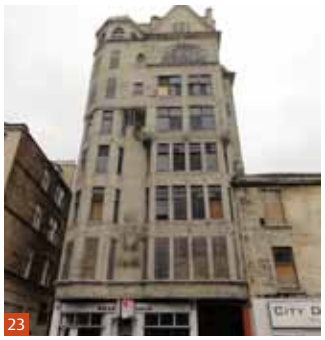
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Precast concrete:

- Cast in a reusable mould or 'form' and then cured
- Generally durable and long lasting
- Used for building components from mid 19th century onwards
- Commonly painted to imitate stone features on masonry buildings

3.4 Reinforced concrete

Origins

Concrete on its own has a low tensile strength limiting its use as a structural material. The inclusion of metal embedded within concrete increases its resistance to tensile stress and is known as reinforced concrete. Wrought iron was initially used but was generally replaced by steel after 1890. The first successful use of reinforced concrete in a building in Britain was William Wilkinson's house in Newcastle (c.1860), where wire ropes were used to provide the necessary tension in the ceiling. When the house was demolished in 1954 the ropes were found to be still in good condition (Stanley, 1979). The earliest examples of reinforced concrete in Scotland are predominantly from between 1886 and the beginning of the 20th century (commonly referred to as 'ferro-concrete' at the time). An early example of reinforced concrete being used in urban water infrastructure is the Category B listed aqueduct at the Parkhill Pumping Station in Newmachar, Aberdeenshire. Dating from 1898 the aqueduct is reported to be one of the earliest reinforced structures in Scotland (Fig 21).

The early growth of reinforced concrete in the UK relied upon patented systems being pioneered in France, Germany, United States and England; and many different systems were used. In Scotland, six systems have been identified: Coignet; Considère; Hennebique; Patent Indented Steel Bar Co. (Indented Bar); Trussed Concrete Steel Co. (Kahn) and Wells (Borden, 2010). Some examples include early cantilevered reinforced concrete ramps – unfortunately now demolished – in a courtyard in Bon Accord Street, Aberdeen (1889); the vaulted roof to St Sophia's church in Galston, East Ayrshire (c 1886); the Hennebique system for the Sentinel Works in Glasgow (1903-04); and the Considère system for balconies and foundations to the Usher Hall, Edinburgh (1910-14). The most common system used in Scotland was the Hennebique system, essentially a frame with infill floor slabs and external wall infill panels or cladding in brick, stone or concrete. Continuity of reinforcement provided rigidity at haunched column and beam joints and allowed cantilevers to be constructed. Examples of buildings constructed using the Hennebique system include Category A listed 17 Vinicombe Street in Glasgow (Fig 22) and Category A listed 170,172 Hope Street in Glasgow, also known as Lion Chambers (Fig 23), which is an important example of Glasgow style Art Nouveau. As reinforced concrete developed throughout the 20th century it was used in many other styles including Art Deco, as seen in the Northern Hotel in Aberdeen (Fig 24).


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Fig 21 The aqueduct at the Parkhill Pumping Station, Newmachar (1898) is reported to be one of the earliest examples of the use of reinforced concrete in Scotland.

Fig 22 The Salon, 17 Vinicombe Street, Glasgow (1913). Built as a cinema, but is now used as a bar and restaurant. Constructed using the Hennebique reinforced concrete system, with a cement render and painted finish.

Fig 23 170-172 Hope Street, Glasgow (Lion Chambers) (1905). Glasgow style Art Nouveau, eight-storey commercial building constructed using the Hennebique reinforced concrete system.

Fig 24 Northern Hotel, Aberdeen (1938). Four-storey hotel with Art Deco detail. Reinforced concrete with squared granite facing, reinforced concrete balconies and cantilevered canopies over the main and rear entrances.

It was perceived that there were two principal advantages offered by reinforced concrete: a financial benefit when compared with steel and masonry, and the protection offered against fire. In addition, it was assumed that embedding the reinforcement in concrete offered it protection against corrosion. Unfortunately, it was later discovered that factors such as the depth of concrete cover to the steel, the mix design (particularly water content) and compaction all had a major impact on durability. Reinforcement corrosion is therefore a significant issue for many early reinforced concrete structures. An example is Lion Chambers, Glasgow where because of the slender nature of the concrete, limited cover to the reinforcement has allowed carbonation to reach the reinforcement resulting in the serious corrosion and spalling (Fig 25). A protective mesh now encases the structure to prevent falls to detached concrete. The building has been declared a dangerous structure and is in risk of demolition. This is considered in more detail in the second and third short guides in this series, '*Investigation and assessment of defects and decay*', and '*Maintenance and repair of historic concrete in Scotland*'.


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Fig 25 170-2 Hope Street, Glasgow (Lion Chambers) (1905). Due the slender nature of the concrete, limited cover to the reinforcement has allowed carbonation to reach the reinforcement resulting in the serious corrosion.

Concrete Floors

Whilst reinforced concrete was not in general use in Britain for building frames before 1890, it was used for lintels and sometimes walls (Hurst, 2001). In addition wrought iron beams were used within concrete floors (Fig 26) and also sometimes within columns generally for fire resistance in industrial buildings. Wrought iron was commonly used before 1890 but was generally replaced by steel after this date. Rolled or fabricated iron joists at a range of spacing supported a variety of infill panels between the joists, often with a coke breeze aggregate, leading in turn to the development of filler joist floors in the 1890s. While durable and fireproof, concrete floors of this type were vulnerable to cracking and damage in the event of corrosion of the iron or steel beams (Fig 27).

Early reinforced concrete bridges in Scotland

An analysis of types of concrete structures in Scotland indicates that concrete bridges are an important part of the concrete built heritage (see Appendix). A comparatively large number of concrete bridges were constructed in the late 19th and 20th century and many of these pioneered the use of reinforced concrete and incorporated innovative designs. The significance of concrete in the construction of bridges in Scotland can easily be overlooked due to the majority of bridges being of masonry construction. The best known extensive use of mass concrete for bridges was on the West Highland Railway (1897-1901); comparatively late for a railway development in the UK.

The development of road infrastructure in the 1920s and 1930s provided an opportunity for pioneering reinforced concrete bridge designs to be built in Scotland. Sir Owen Williams, for example, was responsible for the designs of 'Modern Movement' bridges at

Fig 26 Steading at Ardtornish Estate (c.1880). Spalling on the underside of a concrete floor due to corrosion of the wrought iron joists.

Fig 27 Control Tower, Boyndie Airfield, Banff (1943). Brick walls with reinforced concrete floors, roof and cantilevered balcony. Extensive corrosion of reinforcement has disrupted the ceiling of the intermediate floor.


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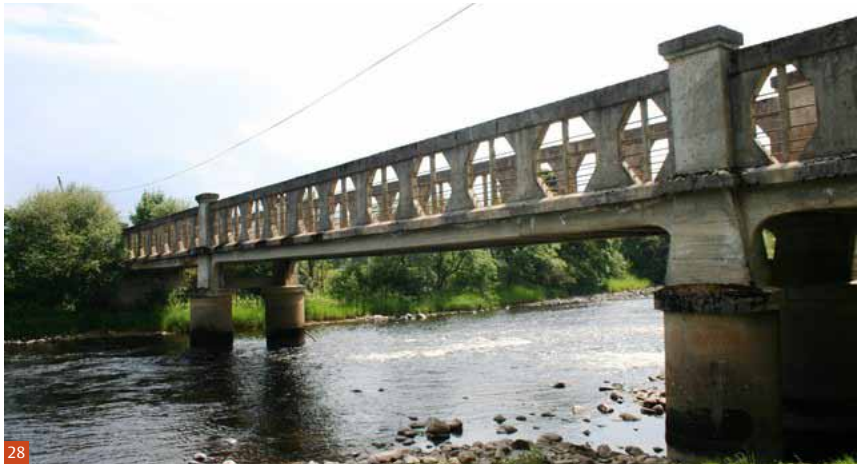
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Fig 28 Advie Bridge over the River Spey, Cromdale, Highland (1921-22). Three-span concrete bridge with reinforced concrete trusses on paired concrete piers.

Crubenmore and Advie (Fig 28), and the bridge over the River Findhorn (Fig 29) carrying the old A9 road at Tomatin. An example of an advanced bridge design of this period is the Category B listed three-hinged portal frame bridge over the River Dee at Aboyne (Fig 30), featuring additional flood arches and precast concrete block parapets. Dating from 1937, it was designed by F.A. Macdonald and Partners Engineers and the architect George Bennet Mitchell.

Reinforced concrete:

- Cast in-situ with the inclusion of metal embedded within the concrete to increase tensile strength
- Wrought iron was initially used but generally replaced by steel after c 1890
- First used for lintels, walls and floors, but achieved general use for building frames and bridges after c 1890
- Earliest examples of reinforced concrete structures in Scotland are from between 1886 and the beginning of the 20th century
- During the early 20th century patented systems allowed the increased use of reinforced concrete, with the Hennebique system commonly used in Scotland
- First national Code of Practice for reinforced concrete in the UK was not introduced until 1948
- Reinforced concrete has developed continuously and has widespread use in modern structures
- Corrosion of reinforcement can be a significant problem in early structures

Fig 29 Findhorn Bridge, Tomatin, Highland (1924-26). Reinforced concrete bridge, with two pairs of in-situ concrete beams joined at a central pier.

Fig 30 Aboyne Bridge (1937). An example of reinforced concrete with precast concrete block parapets.


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3.5 The development of codes of practice for structural concrete

The first attempt to produce what was essentially a Code of Practice (CP) was the 'Report of the Joint Committee on Reinforced Concrete', produced in 1907 by the Royal Institute of British Architects. However, the first national Code of Practice for reinforced concrete in the UK was not introduced until 1948 (Table 1).

Date	Brief titles
1907	Report of the RIBA Joint Committee
1911	Second report of the same RIBA Committee
1916	LCC Regulations
1933	The DSIR Code. Report of the Reinforced Concrete Structures Committee
1938	LCC Regulations
1939	Building Industries National Council Code
1948	CP 114 Reinforced Concrete
1957	CP 114 (with amendments in 1965, 1967 and 1973)
1959	CP 115 Pre4stressed concrete (with amendment in 1973)
1965	CP 116 Pre-cast concrete (with Addendum 1 in 1970)
1972	CP 110 Structural Concrete
1985	BS 8110 Replacing and updating CP110
1992	BS EN 1992 Design of concrete structures, replacing BS 8110

Table 1 An outline of the historical development of the main general codes for structural concrete in the UK (Bussell, 2001).

3.6 Post-1945 concrete construction

While this guide is primarily concerned with the development of concrete construction in Scotland up until 1945, it is nevertheless the case that important developments continued rapidly beyond this date.

Shortages of steel for reinforcement in concrete occurred during the Second World War and the immediate post-war period up until the 1950s, which saw a restriction to the development of concrete. At the same time, the severe damage to the built infrastructure caused by the Second World War made it clear that rapid and economic methods of construction would be required to produce new housing on a massive scale. This necessitated innovative methods of concrete construction and saw the introduction of pre-stressed concrete, initially used for beams. The first recorded use of pre-stressed concrete for buildings in Scotland is the category A listed H. M. Stationery Office in Sighthill in Edinburgh, built in 1949. In this case, both pre-tensioning of beams in a factory and post-tensioning of beams before being lifted into position were employed: a structurally innovative approach using the Magnel system (Burgoyne, 2005).

From the late 1950s a huge expansion in concrete construction began to take place. Various solutions were implemented to increase production of building elements, such as open and closed prefabricated precast concrete systems, mainly Large Panel Systems (LPS), for both low-rise and high-rise housing. These were often imported from Europe; with examples such as Camus from France and Jespersen from Denmark, amongst others, used in Scotland. Early problems with inadequate structural continuity of the panel joints resulted in the progressive collapse of Ronan Point high-rise flats in London due to a gas explosion in 1968. This resulted in revised design codes and strengthening or demolition of vulnerable buildings in Scotland and elsewhere.

Up until the mid 20th century, the design of structures was generally dictated by the architect, the engineering design having to fit into preconceived concepts with respect to structural grid and element dimensions. During the latter half of the 20th century, it became increasingly common for the consulting engineer or design-and-build contractor to be involved at the start of the design process. In some earlier structures this resulted in a lack of specialist concrete design during the early design process, as exemplified in a late 1950s former telephone exchange in Edinburgh (Fig 31). The slender columns and edge beams of this reinforced concrete framed building provide limited cover to the reinforcement with resulting in its corrosion.


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Fig 31 A concrete frame with masonry infill on a 1950s building in Edinburgh. The slender concrete frame provides limited cover to the reinforcement, resulting in its corrosion and cracking of the concrete. © Andrew Wright.

Post 1945 also saw the widespread use of 'no fines' concrete for mass housing in Scotland, mainly by Wimpey and the Scottish Special Housing Association (Fig 32). Off-site manufacture and proprietary precast concrete floor systems proliferated, often reflecting the early concrete flooring systems. Advancements in prefabricated formwork produced sophisticated and fast construction methods such as continuously sliding formwork. This system allows wet concrete to be poured continuously as the movable formwork is slowly lifted upward usually by hydraulic jacks or screw jacks. The technique was fast and economical and used on numerous building projects including 'bespoke' high-rise buildings.

Fig 32 Erection of no fines concrete houses late 1960s. Foreground: two-storey internal shutter ready to receive external shutter and concrete pour.


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4. Characteristics of early concrete

As discussed in chapter 2, early concrete and modern concrete are similar to each other in that both have a combination of constituents: a binding agent, either natural cement in the form of hydraulic lime or Portland cement; fine or coarse aggregate and water. Up until the mid to late 19th century, hydraulic lime was predominately used as the binding agent. Concretes made with natural cements such as hydraulic lime generally have a compressive strength that is significantly less than those made with Portland cement. It is not possible to apply a precise figure to the relative strengths due to the variable nature of these historic cements and early concrete production processes and so each case must therefore be individually assessed.

During the latter part of the 19th century hydraulic lime was becoming increasingly replaced by Portland cement, which is less porous and produces a concrete of greater strength. By the early 1900s the majority of concrete structures used Portland cement. The use of lime did still continue after this period, but it was usually in combination with Portland cement to increase malleability of mortars and plasters. Although concrete produced in the first half of the 20th century used Portland cement, its compressive strength is typically less than concrete produced in the latter half of the century. For a 150mm cube the usual compressive strength would be about 15-20 N/mm^2 (Newtons per square millimetre) (Beckmann and Bowles, 2004), whereas concrete today is normally in the range of 35 N/mm^2 to 70N/mm^2. Improvements in the manufacture of cement, a better understanding of concrete technology and more availability of quality natural aggregates have all led to a significant increase in the strength of concrete.

Aggregate forms around 80% of the total volume of a concrete and its physical and chemical characteristics make an important contribution to the quality of the final mix. Scientific understanding of the role of aggregate was not well developed before 1900 and the presence of deleterious materials, such as clays, organic materials or sea salts, could be common. For these early concretes, the choice of aggregate was limited to what was available locally and it is unlikely that it would have been washed with clean water before use. In Scotland, the foreshore offered a ready source of aggregate, which would be poorly graded, rounded and salt contaminated. Other sources would be gravel from local rivers, streams and gravel pits, crushed brick and even ash; the latter is reported to have been used in East Lothian to produce shuttered ashcrete. Aggregates such as these could contain a high concentration of salts resulting in efflorescence on the surface and crypto-florescence within the pores (which is more damaging) resulting in corrosion of reinforcement and a concrete that was of variable quality. Beckmann and Bowles (2004) report that certain late 19th and early 20th century concrete floor structures were made using coke clinker as the aggregate. Such an aggregate includes unburnt coal residues, which contain sulphur, and can thus cause corrosion of any embedded reinforcement.

During the late 19th century a form of 'no fines' concrete was sometimes used for wall construction in housing projects. A good example of this is the innovative no fines mass concrete tenements built by David Clunas and the Concrete Building Company in Court Street, Dundee in 1874 (Fig 33). It is unclear how this concrete was designed, mixed and placed or what its properties are. However, the buildings appear to remain in a sound structural condition.

Another essential component of concrete is water. While in modern concrete manufacturing the cleanliness and volume of water required is understood and controlled, this was not the case with early concrete. Water for mixing may have been taken from any convenient source and could have had a detrimental effect to the finished concrete. Also, the amount of water included was not carefully controlled, with a tendency to produce wet mixes and thus create concrete containing a high proportion of voids. The evaporation of excess water results in an increase in porosity, which reduces strength and allows the damaging ingress of air and moisture. The detrimental effects caused by voids in concrete were established by Vicat in the 1830s, but it was not until after c 1915 that this became more generally appreciated (Reed et.al, 2008).

The amount of water introduced was also influenced by the available mixing and compaction methods. Up to the late 19th century, mixing and compaction was done by hand. This required more water in the mix, leading to considerable variations in the quality of the finished concrete. While mechanically powered mixers were becoming available from the early 20th century, these tended to be used only on the larger construction sites (Marsh, 1905) whereas, for small or remote sites, hand mixing and compaction was still common practice.

Early concrete, whether with a lime or cement binder, tends to be lighter in colour than modern concrete produced using standard grey Portland cement. However, the colour of the finished concrete will be influenced by the nature of the aggregate employed, especially when using fine aggregate. For example, concrete produced from clinker or crushed brick will produce a colour tone that reflects the embedded constituents. While the lighter colour of early cements may be identified when the core of the concrete is exposed, the colour of an external surface will have been influenced by its ambient environment, exposure and weathering.

All concrete weathers over time and identification of the binder by colour alone should be avoided. The actual appearance of historic concrete tends to be very inconsistent, in both colour and texture, because of natural weathering due to rain, wind and frost eroding the surface cement film and exposing the different colours of the aggregates. Also, the weathered and roughened surface will encourage the attachment of both particulate and biological soiling which will also alter the surface appearance.


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Fig 33 No fines tenements in Court Street, Dundee (1874-75).

When dealing with early concrete buildings it is clear that establishing the date of construction could be an important aspect in any analysis of the characteristics of the material. For example, it is useful to note that the early examples of reinforced concrete were proprietary systems, which flourished until the London County Council adopted reinforced concrete regulations in 1915 (Borden, 2010). The first Code of Practice for Reinforced Concrete was published in 1934 (Concrete Society, 2009) and the first guidance for bridges was issued by the Ministry of War Transport in 1945. Slightly earlier, the first edition of 'Reinforced Concrete Designers Handbook' by Reynolds was published in 1932. This proposed a series of concrete mixes with proportions ranging from 1:3:6 up to 1:1:2, although cube strengths are not identified.

The fact that most of the listed buildings with reinforced concrete elements (see Appendix) were constructed before the introduction of a relevant code of practice will inevitably mean that there could be significant differences in the design and construction of the elements. Therefore, generalised assumptions as to the composition, design and durability of these early building elements should not be made.

Summary of early concrete characteristics:

- Concrete with a lime binder is typically weaker and more porous than that made with a Portland cement binder
- Concrete (with a cement binder) in the first half of 20th century typically has a compressive strength of around 15-20 N/mm2
- Understanding of the role of aggregates was not well developed before 1900
- Water-cement ratio was not carefully controlled, and hand compaction produced concretes with a high proportion of voids
- In concrete analysis, date of construction is a useful indicator of the possible general characteristics
- Generalised assumptions of composition, design and durability of early concrete should not be made without a detailed analysis

5. Principles for the repair of historic concrete

When compared with traditional masonry, concrete buildings and structures are features of the comparatively recent past, although many are now in excess of 150 years old. To properly determine the approach to their conservation will mean that some of the principles adopted for masonry conservation may need to be looked at in a different light. For example, whilst masonry constructed of individual, small-scale units may be amenable to progressive consolidation and replacement this is not the best approach for the conservation of homogeneous structures and elements formed in concrete. It is necessary to understand the approach to the design and construction of these buildings to be able to fully appreciate their significance to the history of the built environment. The significance can lie in the architecture, pioneering engineering, innovative use of materials, construction techniques, or a combination of these.

Assessment of previous repairs can also present significant issues when developing a conservation strategy. For example such interventions may have been carried out as emergency work to keep the structure functioning and will have frequently been done as patch repairs, the more recent having been carried out using modern materials and techniques. Previous repairs can result in an obvious change in appearance, particularly on smooth faced concrete, and the use of an incompatible material can also affect the future performance of the concrete. The different appearance of the new finish can be difficult to prevent but is not necessarily a conservation issue: it represents the building 'as conserved'. Nonetheless, poorly executed repairs may require correction in the future. An example of this is the patch repairs to the harbour wall at the New Harbour, Portsoy (Fig 34), which have been poorly matched to the original face.


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Fig 34 The New Harbour at Portsoy (19th century) showing a poorly matched modern repair to the face of the sea wall.

A further consideration in developing an appropriate conservation strategy is that many concrete structures are not simply monuments to the past but play a vital role as a still-functioning part of the country's infrastructure, such as bridges, harbours, dams and aqueducts. This means that any interventions, while respecting the original, must ensure that any work carried out can withstand the often very considerable and increasing stresses imposed during future use, such as increasing traffic loads on bridges and severe winter storms on harbour walls. In addition, inadequate maintenance in the past could mean that repairs may have to be carried out with some urgency to allow the building or structure to continue to meet its critical function. Nevertheless, the need for urgent intervention should not mean that this is carried out in a way that contravenes good conservation practice.

Essential knowledge required prior to considering repairs to original concrete should include an understanding of:

- Binder characteristics
- Mix proportions
- Nature of the aggregates
- How the formwork was designed
- Design, type and positioning of any reinforcement
- Nature of any precast elements (which may be different from mass concrete elements)
- Past repairs

6. Summary

As can be seen from this document, concrete has a varied and important presence as a building material in Scotland. This guide intends to provide knowledge and understanding of concrete as building material on which to base informed principles of repair and conservation.

However, before any work is carried out it is essential that the condition of the concrete is fully understood and the causes of any deterioration detected. The next guide in this series, *Investigation and assessment of defects of historic concrete in Scotland* goes into more detail on assessing the condition of concrete buildings in Scotland and identifying causes of defects and decay.

7. Contacts and further reading

Contacts

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8. Appendix: Early concrete structures in Scotland

Examples of early concrete buildings in Scotland

The list below (Table 1) provides details of mass and reinforced concrete structures in Scotland. Some precast concrete examples are also included. The list does not include examples of mass concrete built later than 1920 or reinforced concrete later than 1945. In compiling the list, the vast majority of citations were drawn from Historic Scotland's database of listed buildings. In addition, there are examples of unlisted buildings, most of which are identified by Stirling (2001). It should be noted that the list does not include all concrete buildings in Scotland and should not be considered definitive.

Region	Structure Type	Cat	Date	Address	Comments
Aberdeen	*Building*	*B*	*1937*	*Bon Accord Baths, Justice Mill Lane*	*Art deco, shallow segmented vaulted concrete roof on concrete piers, concrete galleries*
	Building	*B*	*1889-1908*	*11a-19 Bon Accord St , Courtyard*	*Early, advanced cantilevered RC ramps on 2 levels. Steel beams and concrete arch construction cantilevered over courtyard (ramps now removed)*
	Building	*B*	*1875*	*17-21 Kings Crescent and 1 Jute Street*	*Early concrete terrace of 3, 2-storey houses with rendered finish*
	Building	*A*	*1872*	*Tivoli Theatre, Guild Street*	*Side, rear and party walls of mass concrete*
	Building	*A*	*1938*	*1 Great Northern Road, Northern Hotel*	*Art deco 4 storeys RC with granite facing. RC cantilevered canopies at main entrance*
	Building	*C*	*1892*	*City Hospital, Urquhart Road, East and West Pavilions*	*Part of pavilion constructed of concrete*
	Building[1]	*B*	*1912*	*Broadford Mills, Maberley Street*	*Converted former flax store, RC columns, floors and roof. Brick and RC Hennebique system*
	Building[1]	*B*	*1910*	*208, 210 Union Street*	*Former Royal Insurance building RC elements, Hennebique system*
	Building[1]	*C*	*1912*	*Ashley Road School*	*RC elements, Hennebique system*
	Building[1]	*A*	*1912-13*	*Robert Gordon College, East Wing*	*Reconstruction of East Wing, RC elements, Hennebique system*
	Lighthouse	*A*	*1880-90*	*Girdleness Lighthouse including Fog Signal, Greyhope Road*	*Cast iron on concrete block podium*
	Lighthouse	*NL*	*1870-73*	*Lighthouse, South Breakwater, Aberdeen Harbour*	*Tapering circular mass concrete tower*

Table 1 Examples of pre-1945 concrete buildings in Scotland. Abbreviations: RC = Reinforced Concrete; CI = Cast Iron; NL = Not Listed. Additional details from the list of reinforced concrete buildings identified in Borden (2010), identified as 1; PhD thesis of Stewart Stirling, Heriot-Watt University 'Early concrete buildings in Scotland', 2001; John Duncan formerly Conservation Officer, Highland Council (private correspondence)

Region	Structure Type	Cat	Date	Address	Comments
Aberdeenshire	*Building*	*B*	*1911*	*Udny, Tillycorthie Mansion House*	*Unusual early concrete two-storey and basement. Concrete mullioned windows*
	Building	*NL*	*1911*	*Udny, Pump House, Tillycorthie estate*	*Originally single-storey RC pump house, converted to single dwelling house*
	Building	*B*	*1934*	*Stonehaven swimming pool*	*Painted concrete buildings*
	Building	*NL*	*c1890*	*Byre, Mayfield Farm Nr Rosehearty*	*Walls to 1m height shuttered mass concrete, left exposed*
	Building	*C*	*Late 19th century*	*1-18 Campbell Street, Banff*	*Single storey and attic houses, concrete dressings and concrete copes to end stacks*
	Building	*C*	*1897*	*39 Castle Street, Banff*	*Whinstone walls with concrete dressings and margins*
	Building	*C*	*1884*	*3 Institute Street, Portsoy*	*2 storey hall, painted concrete dressings, coped concrete end stacks*
	Building	*NL*	*c1900*	*14 and16 Hill Street, Portsoy*	*Early precast concrete window and door dressings*
	Building	*NL*	*1897*	*Fordoun, 1-8 Springbank Terrace*	*Single storey cottages. Probably shuttered mass concrete, rendered finish*
	Building	*NL*	*Late 19th century*	*Fordoun, 9 and 10 Springbank Terrace*	*2 storey semi-detached houses, probably shuttered mass concrete, now dry dash finish*
	Building	*NL*	*c1900*	*Fordoun , Workshop, Springbank Terrace*	*Single storey. North end shuttered concrete*
	Building	*NL*	*c1900*	*Fordoun,Rowan Cottage, Station Road*	*Single storey cottage, mass concrete walls, cement rendered*
	Building	*B*	*1943*	*Boyndie Airfield, Control tower*	*Brick with concrete cantilevered balconies*
	Building	*B*	*1943*	*Boyndie Airfield, Operations Block*	*RC roofs*
	Bridge	*B*	*1937*	*Aboyne Bridge, over River Dee, Bridgeview Road, Aboyne*	*3-hinged RC portal frame bridge, RC abutments*
	Aqueduct.	*B*	*1898*	*Newmachar, Parkhill Pumping Station, lade, aqueduct and tanks*	*Mass concrete pumping station, 2 large RC arches in aqueduct. Possibly one of earliest uses of reinforced concrete in Scotland*
	Bridge	*C*	*1879-92*	*White Bridge, Arbuthnot Street, Stonehaven*	*1892 concrete floor*
	Bridge	*B*	*1935*	*Auchmacoy Memorial Bridge*	*RC pedestrian bridge over River Ythan*
	Bridge	*B*	*1935*	*Dinnet, Bridge over River Dee*	*RC Art Deco bridge*
	Building	*C*	*1897*	*36 Castle Street, Winston House, Banff*	*Painted concrete margins and dressings*
	Harbour	*B*	*1825 and 1884*	*New Harbour, Portsoy*	*Rubble and concrete with concrete sea wall*
	Harbour	*B*	*Late19th century*	*Rosehearty Harbour*	*Some concrete, small circular concrete beacon*
	Harbour	*A*	*1770 and early 20th century*	*Banff Harbour and Pillbox*	*Concrete cap to pillbox*
	Lighthouse	*NL*	*c1880*	*Fraserburgh, light tower, end of North Pier*	*Tall tapering tower*
	Lighthouse	*NL*	*c1900*	*Macduff Harbour, End of East Pier*	*Large tapering mass concrete tower*
	Lighthouse	*B*	*c1900*	*Peterhead harbour, end of South Breakwater*	*Listed as part of harbour, concrete light tower*
Argyll and Bute	*Lighthouse*	*NL*	*Late 19th century*	*Crinan, Light tower, entrance Crinan harbour*	*Hexagonal cement rendered concrete tower*
	Rail viaduct	*A*	*1880*	*Falls of Cruachan Viaduct, Ardchattan and Muckairn*	*Mass concrete arches. First on British railways with mass concrete arches*
	Building	*C*	*Late 19th century*	*Blairmore Farm*	*Relatively rare concrete structures including a pair of concrete cottages*
	Building	*B*	*1870s*	*Benmore Home Farm,Strone.*	*Concrete cottages at Benmore Home farm*
	Sewage Works and Public Convenience	*B*	*1930*	*Mount Stuart Road, Rothesay*	*Raised concrete base course, domed concrete roof concrete surrounds to openings*

Region	Structure Type	Cat	Date	Address	Comments
Borders	*Building*	*B*	*1869*	*Waverley Road, Tweed Cottage, Melrose*	*2 dwellings, mass concrete*
	Building	*B*	*1869-71*	*Waverley Castle Hotel, Melrose*	*4 storey mass concrete, rendered concrete detailing. Possibly earliest mass concrete building in Scotland*
	Building	*C*	*1903*	*1 Buccleuch St, Innerleithen Public Library, Innerleithen*	*Precast bull-faced concrete blocks with sandstone margins to main elevations*
Clackmannanshire	*Building*	*NL*	*c1870*	*Lornshill Cottages, nr Alloa*	*2 single storey semi-detached cottages, mass concrete cement rendered*
	Building	*A*	*1936*	*Kilncraigs Warehouse, Greenside Street, Alloa*	*International modern style. Whitewashed RC with steel superstructure attached to 1903 warehouse*
	Power Station and Bridge	*B*	*1934*	*Glenlee Hydro Power Station, Kells*	*Painted RC bays and 2 arch concrete bridge*
Dundee	*Building*	*C*	*Early 19th century*	*158 St Vincent St, Broughty Ferry*	*3 bay Cottage, painted concrete dressings, concrete coped ashlar ridge stacks*
	Building	*C*	*Early 19th century*	*160 St Vincent St. Broughty Ferry*	*3 bay Cottage, painted concrete dressings, concrete coped ashlar ridge stacks*
	Building	*C*	*Mid 19th century*	*14 and 16 Fort Street, Broughty Ferry*	*Painted concrete margins and skew coping*
	Building	*C*	*1850*	*1 Ambrose Street, Broughty Ferry*	*Painted concrete margins*
	Building	*B*	*1890*	*82-86 Broughty Ferry Road, Dundee*	*4 storey flat roofed tenement. Concrete roof*
	Building	*B*	*1874-75*	*1-23 (Odd Nos) Court Street (The Connies), Dundee*	*Early innovative no fines mass concrete tenements Built by David Clunas and the Concrete Building Company. Renovated and buff rendered 1982-84*
	Building	*A*	*c 1875*	*Beachtower, 6 Ralston Road, West Ferry*	*2 storey and tower, shuttered mass concrete, cement render finish*
	Building	*NL*	*1876*	*Moyness, 76 Grove Road, West Ferry*	*2 storey, 3 bay villa, shuttered mass concrete, cement rendered and masonry paint*
	Building	*A*	*1907*	*2, 4 Candle Lane and 99 Seagate and 25-27 (odd) Trade Lane, Watson's Bond, HM Customs Warehouse*	*4 and 5 storey brick clad part RC frame. Hennebique system*
	Building	*B*	*1913*	*80-100 Cowgate, East Port Calender Works*	*RC framed ribbed concrete first floor*
	Building[1]	*A*	*1914-15 and 1918*	*Caird Hall*	*RC frame, flooring and engine house. Hennebique system*
	Building	*B*	*1882*	*Anchor Lane, South Anchor Mill*	*Early use of concrete arched floors*
	Building	*B*	*1902*	*22 Meadowside, D C Thomson Courier Building*	*First use in Scotland of Hennebique reinforced concrete piles*
	Harbour	*A*	*1833*	*Dundee Harbour*	*Reported use of mass concrete by Telford (Historic Scotland TAN 6)*
	Harbour	*B*	*1890*	*Dundee Harbour, Caledon West Wharf*	*First RC wharf in Scotland, Hennebique system*
	Harbour	*B*	*1849-51*	*Broughty Ferry Harbour*	*Concrete-faced buttresses.*
	Harbour	*B*	*1872*	*Broughty Ferry, Fisher Street Quay and Pier*	*RC extension seaward*
Dumfries and Galloway	*Bridge*	*B*	*1900*	*Powfoot Bridge and retaining walls*	*Bridge is early example of concrete beam construction*
	Lighthouse	*A*	*1889*	*Corsewell lighthouse, Kirkholm*	*Foghorn set on raised concrete platform and continued round base of engine house*
	Building	*B*	*Mid 19th century and 1920 silo*	*Baltersan Steading and Silo*	*1920 concrete silo*
	Building	*B*	*1913*	*Heathall Uniroyal factory*	*3 storey ferro concrete frame*
East Ayrshire	*Building*	*A*	*1886*	*St Sophia's Roman Catholic Church, Galston*	*Early example of RC for vaulted*

Region	Structure Type	Cat	Date	Address	Comments
East Lothian	*Bridge*	*B*	*1912*	*Westfield footbridge over River Tyne, Haddington*	*Entirely reinforced concrete*
	Harbour	*B*	*1880s*	*Port Seton Harbour*	*Concrete tidal harbour. Early example of mass concrete*
	Building	*C*	*Mid 18th century*	*Golf Cottage Aberlady Main Street, Aberlady*	*Rubble walls with concrete margins*
	Building	*B*	*1886*	*Beesknowe House, Biel, Stenton*	*Shuttered ashcrete with plaster between mock timber framing*
Edinburgh	*Harbour*	*B*	*1876-78*	*Newhaven Harbour*	*Curved concrete breakwater. North Quay concrete heightening*
	Building	*A*	*1949-50*	*HMSO Store Bankhead Broadway, Sighthill*	*Structurally innovative pre-stressed concrete frame*
	Building	*A*	*1911-12*	*Royal Scottish Academy, Princes Street*	*Coved concrete ceiling to upper galleries in 1911 extension*
	Building	*A*	*1910-14*	*Usher Hall*	*Concrete, steel and brick construction clad with stone*
	Building	*C*	*Late 18th century*	*1-4 Peacock Court*	*Precast skews and concrete cope*
	Building	*B*	*1932*	*11 Easter Belmont Road*	*RC Canopy*
	Building	*A*	*1899-1902*	*20-52 North Bridge, 65-71 Coburn St*	*Concrete clad floors*
	Building	*A*	*1906*	*90-102 Inchview Terrace, Portobello Road*	*3 storey Arts and Crafts technical institute, R C Framed. First half-dozen RC multi-storey buildings in Scotland. E P Wells patented system*
	Harbour	*B*	*1853-63*	*Granton Harbour, East Breakwater*	*Concrete steps down east side. WW2 concrete lookout post.*
	Bridge	*A*	*1883-90*	*Forth Bridge*	*Concrete and masonry piers*
Falkirk	*Building*	*C*	*1936-3 7*	*1-11 Seaview Place, Bo'ness*	*Flats, modern movement, buff concrete block work*
	Harbour	*C*	*1878-81*	*Union St harbour, Falkirk, A904*	*L-plan concrete east pier. Concrete walled dock*
	Harbour	*A*	*1900*	*St Andrews Harbour*	*Concrete terminal to pier. Built on earlier works from 1559*
Fife	*Rail Bridge*	*C*	*1909*	*Stirton railway bridge, Kilmany*	*Elliptical arched mass concrete, precast concrete skewbacks*
	Bridge	*B*	*1930-32*	*Glen Bridge over Tower Burn Dunfermline*	*RC Single span bridge*
	Lighthouse	*B*	*1896*	*Oxcars Lighthouse, Aberdour*	*Brick lighthouse but mass concrete landing stage and pier (1894)*
	Building	*C*	*1938*	*RAF Leuchars, former ops block, Building 181*	*Original concrete roof*
	Building	*B*	*1909*	*Ferryhills Road, Naval Base Mansions, Jamestown*	*Hennebique RC system for beams landings etc*
	Building	*A*	*1917-18*	*RAF Leuchars, Buildings 55 and 57*	*RC floors*
	Building	*C*	*1939*	*RAF Leuchars, Building 213*	*Flat roofed modernist, RC and Brick internal walls*
	Building	*A*	*Early 20th century*	*Inchcolm Abbey, Ancillary buildings*	*Concrete gun emplacements*
	Building[1]	*B*	*1914-15*	*Dunfermline, Abbot Street, Carnegie Central Library*	*RC elements, floors, arched roof of central hall, columns, staircases, foundations. Hennebique system*
	Building[1]	*NL*	*1919*	*Kirkcaldy Malthouse*	*RC interior and upper part of kilns. Hennebique system*
	Harbour	*B*	*1866-77*	*Anstruther Harbour*	*Masonry and concrete, incorporates parts of old harbour*
	Airfield	*A*	*1939-40*	*Crail Airfield. Various Buildings*	*Associated brick, concrete and iron structures*

Region	Structure Type	Cat	Date	Address	Comments
Glasgow	*Rail Bridge*	*B*	*1903*	*Old Castle Road, bridge over Cart , Glasgow*	*Main span mass concrete*
	Building	*A*	*1882*	*105-169 Bell Street*	*Colossal 6 storey warehouse. CI beams supporting mass concrete arches*
	Bridge	*C*	*1930*	*Balmore Road, Lambhill Bridge*	*Concrete abutments and wing walls*
	Bridge	*B*	*c 1903*	*Old Castle Road Rail bridge*	*Main span mass concrete (McAlpine)*
	Bridge	*B*	*1924-28*	*King George V Bridge*	*Reinforced concrete bridge, 3 segmental arches, 146ft main span*
	Building	*A*	*1903-04*	*61 Jessie Street, Sentinel Works*	*Early ferro-concrete pattern store of Hennebique system, 4 storeys, concrete panel walls*
	Building	*A*	*1895*	*16 McPhater Street, Cowcaddens*	*Warehouse, 4 storey, 8 bay, Iron frame, mass concrete walls, cement rendered and painted*
	Building	*B*	*1898-99*	*Napier House, 638-646 Govan Road*	*Modern movement 4 and 5 storey lodging house, part steel frames, concrete walls and floors*
	Building	*B*	*1931 and 1938*	*Kelvin hall, Arena, Glasgow*	*Concrete RC vaulting and roof trusses to exhibition hall*
	Building	*A*	*1913*	*17 Vinicombe Street, Salon Cinema*	*One of only 2 cinemas constructed using Hennebique ferro-concrete system*
	Building	*A*	*1908-10*	*25 Rose Street, St Aloysius Church*	*Notable for use of concrete roof*
	Building	*C*	*1912*	*3 Tinto Road*	*Coursed bull-faced concrete blocks to boundary wall*
	Building	*B*	*1936*	*480A and 480B Commercial Bank, Gallowgate, Elcho St*	*RC Layout*
	Building	*B*	*1914*	*87,91 Holmfauld Road, Linthouse buildings*	*3-storey RC frame*
	Building[1]	*NL*	*Early 20th century*	*Cook Street, Tradestoun. Telephone exchange*	*Considère system. Masonry facing*
	Building[1]	*B*	*1914*	*42 Spean Street, Cathcart Works, The Wallace Scott Tailoring Institute*	*RC frame, Considère system. Brick infill panels*
	Building[1]	*A*	*1914-16*	*Ingram Street, Head Post Office*	*RC elements, Hennebique system. Converted to retail complex in 2000*
	Building[1]	*B*	*Early 20th century*	*149 Newlands Road. Weir Group Admin building*	*RC elements. Trussed Concrete Steel Co. (Kahn)*
	Building	*A*	*1912*	*Glasgow Green Templeton Carpet Factory*	*RC above ground floor (Hennebique system) also floors to warehouse*
	Building	*A*	*1905*	*170,172 Hope St, Lion Chambers*	*8 storey Art Nouveau, Reinforced concrete*
Highland	*Rail viaduct*	*A*	*1901*	*Arisaig Borrodale*	*Single span mass concrete. Longest single span concrete in world when opened*
	Rail viaduct	*A*	*1901*	*Glenfinnan*	*21 arched concrete viaduct. Longest concrete viaduct in Scotland*
	Building	*B*	*1900-01*	*Glenfinnan Railway Station*	*Single storey Swiss chalet style station building of reinforced concrete*
	Building	*A*	*1905-59*	*Power house Kinlochleven, Lismore and Appin*	*Single storey building, RC frame, Hennebique system*
	Building	*B*	*1890*	*Lochaline 1-5 High St, Morven*	*Mass concrete terrace of 2 storey houses*
	Building	*B*	*1877-78*	*Ardtornish Estate, Claggan School and schoolhouse*	*Rendered concrete*
	Building	*C*	*Late 19th century*	*Ardtornish Estate, Larachbeg old laundry, Morvern*	*2 bay, twin gabled rendered concrete*
	Building	*B*	*1861*	*Ardtornish Estate Durinemast, Morvern*	*Moulded concrete copes*
	Building	*B*	*1873*	*Ardtornish Estate Castle cottages*	*2 single storey houses, rendered concrete*

Region	Structure Type	Cat	Date	Address	Comments
Highland continued	*Building*	*B*	*1879*	*Ardtornish Estate Bay cottage, Inninbeg*	*Rendered concrete*
	Building	*A*	*1884-91*	*Ardtornish Estate Ardtornish Tower, mansion and Clock tower*	*Semi-circular range of game larders, concrete core ashlar rubble fronted*
	Building	*B*	*1880*	*Ardtornish Estate Achranich Manager's house and estate office*	*Rendered concrete*
	Building	*C*	*1892*	*Ardtornish Estate Acharn farmhouse*	*Rendered concrete lined as ashlar*
	Building	*B*	*1875*	*Ardtornish Estate cottages 1-6 Larachbeg*	*Rendered concrete*
	Building	*NL*	*1871*	*Ardtornish Estate, Achranich, coach house and stables*	*2 storey agricultural building, mass concrete, rendered finish*
	Building	*NL*	*1890-1900*	*Ardtornish Estate, Achranich steading*	*Range of concrete steading buildings, smooth render finish*
	Building	*NL*	*1879*	*Ardtornish Estate, Caolas Ferry Cottage,*	*Former stables now cottage*
	Building	*C*	*1879*	*Ardtornish estate, Caolas Ferry House*	*Single storey concrete rendered*
	Building	*NL*	*1902-03*	*Ardtornish estate, Claggan Cottage*	*Single storey, rendered concrete, paint finish*
	Building	*NL*	*1874*	*Ardtornish Estate, Gardener's cottage*	*Single storey cottage, concrete rendered*
	Building	*NL*	*Late 19th century*	*Ardtornish estate, former kennels*	*Shuttered mass concrete, cement rendered finish*
	Building	*NL*	*1899*	*Ardtornish Estate, Kinlochaline cottages*	*Pair of 2 storey cottages, concrete walls cement rendered*
	Building	*NL*	*1895*	*Ardtornish estate, Riverside cottages, Achranich*	*Pair of 2 storey semi-detached cottages, concrete*
	Building	*NL*	*1890-1900*	*Shore cottage, lochaline, Morvern*	*2 storey house, concrete with cement render*
	Building	*NL*	*1890-1910*	*St Kilda, High Street, Lochaline*	*2 storey house, concrete, smooth cement render*
	Building	*NL*	*c1880*	*Glencripesdale Estate, Morvern*	*Barn. Shuttered mass concrete walls cement render finish*
	Building	*NL*	*1880*	*Glencripesdale Estate, Glencripesdale farmhouse, Morvern*	*2 storey concrete extension to earlier farmhouse, cement rendered and paint finish*
	Building	*NL*	*c1870*	*Glencripesdale Estate, Former kennels*	*Range of kennels, concrete rendered. Concrete incorporates large bonding (plum) stones. Now ruin*
	Building	*NL*	*1878*	*Glencripesdale Estate, Former gardener's cottage, Morvern*	*Shuttered concrete cottage/bothy, rendered finish*
	Building	*NL*	*c1870*	*Glencripesdale Estate, Generator shed*	*Original building extended upwards with shuttered mass concrete*
	Building	*NL*	*1878*	*Glencripesdale Estate, Glencripesdale House (remains)*	*Demolished 1963, was 3 storey house, shuttered mass concrete walls cement render finish*
	Building	*B*	*Late 19th century*	*Glencripesdale House, Ardgour*	*Circa 1800 house with later rectangular concrete addition*
	Building	*NL*	*1880-90*	*Barn at Kinloch, Kinlochteacuis, Morvern*	*2 storey, shuttered mass concrete, cement rendered*
	Building	*NL*	*1880-90*	*Field Barn, Laudale Estate, Morvern*	*2 storey concrete barn*
	Building	*NL*	*c1880*	*Laudale Estate, Former cottage*	*Single storey ruin, concrete*
	Building	*NL*	*Late 19th century*	*Laudale Estate, Laudale House, Morvern*	*3 storey farmhouse, concrete storey added to traditional construction, cement render painted*

Region	Structure Type	Cat	Date	Address	Comments
Highland continued	*Building*	*NL*	*c1880*	*Laudale Estate, Farm steading, Morvern*	*Various buildings, some mass concrete with exposed finish*
	Building	*NL*	*19th century*	*Laudale Estate, Upper Liddesdale cottage, Morvern*	*Single storey, concrete, cement render painted*
	Building	*NL*	*1899*	*Former piermaster's house, Lochaline*	*2 storey, concrete with cement render finish*
	Building	*NL*	*c1881-82*	*Crossbeg cottage, Gleann Dubh, Morvern*	*Single storey cottage, concrete with smooth cement render*
	Building	*NL*	*c1890 -1910*	*Doctor's house and surgery, Lochaline, Morvern*	*2 storey house, concrete walls cement rendered, paint finish*
	Building	*NL*	*c1890*	*Lochaline farm steading, Lochaline, Morvern*	*Farm steading, shuttered concrete, cement render finish*
	Building	*NL*	*1890-91*	*Mine Lodge, Lochaline, Morvern*	*2 storey lodge house, mass concrete, cement render and paint finish*
	Building	*NL*	*1880*	*Sutherland Estate, farmhouse and steading, Nr Kinbrace*	*3 bay, 2 storey farmhouse, shuttered mass concrete cement render finish*
	Building	*B*	*1902*	*North Ballachulish, Dunbeg House*	*Stone and mass concrete balcony*
	Building	*B*	*1857-59 and 1896*	*Roshven House, Arisaig and Moidart*	*Mansion house, 1896 works include concrete window surrounds, dormers, corbels and chimney caps/cowls*
	Building	*B*	*1901*	*Railway houses Mallaig, Glenelg*	*4 blocks of houses with concrete lintels*
	Building	*B*	*1900*	*Isle of Rhum, Kinloch Castle, Gazebo*	*Octagonal harled concrete with rendered concrete dressings*
	Building	*C*	*1844*	*Rosehaugh Estate Garden Walls, Avoch*	*Coarse concrete moulded cope to wall with medium sized pebble aggregate*
	Building	*B*	*1931*	*Inverness High School*	*RC frame, modern movement long symmetrical 2 storey block*
	Building	*B*	*1902-03*	*Dunbeg House, North Ballachulish, Kilmallie*	*3 storey house with stone and mass concrete balcony*
	Building	*C*	*c1940*	*Fearn RN Air station Control Rower*	*Brick and RC construction*
	Station	*B*	*1897*	*Duncraig halt, Lochalsh*	*Short single mass concrete faced platform*
	Bridge	*B*	*1932-33*	*Bridge over Oich, Boleskin and Abertarff*	*3 arched concrete bridge, concrete cut waters*
	Bridge	*B*	*1932-33*	*Nevis Bridge (new) over River Nevis*	*Single span concrete*
	Bridge	*B*	*c1900*	*Isle of Rhum, Kinloch Castle Bridge over Slugan Burn*	*Single arch concrete bridge*
	Bridge	*B*	*1932*	*Invergarry, Bridge carrying A82 over River Garry*	*Concrete single segmental arch*
	Bridge	*B*	*1930-35*	*Whitebridge, New Bridge, Boleskin and Abertarff*	*Single span, concrete faced with rubble*
	Bridge	*B*	*1934*	*Fort Augustus, Road bridge, A82 over R Oich*	*3 span RC rubble faced*
	Bridge	*B*	*1924-26*	*Findhorn Bridge, Old A9 over River Findhorn, Tomatin*	*Concrete deck, concrete abutments and parapet*
	Bridge	*B*	*1931*	*Spey Bridge, Cromdale*	*Single span concrete, concrete parapet*
	Bridge	*B*	*1921-22*	*Advie Bridge over River Spey*	*3 span concrete bridge with RC trusses*
	Bridge	*B*	*1925-26*	*Crubenmore Bridge*	*2 arch RC modern movement bridge (similar to Loch Alvie) Bridge)*
	Bridge	*B*	*1931-32*	*Etive Bridge on A82*	*Single bow truss RC bridge*
	Rail bridge	*B*	*1870-71*	*Rail bridge over River Brora, Brora*	*Single span with some concrete buttressing*
	Rail viaduct	*B*	*1897*	*Bridge over R Morar, Falls of Morar, Arisaig*	*3 span concrete bridge, concrete parapet*
	Rail viaduct	*B*	*1901*	*Loch Nam Uamh Viaduct over Gleann Mama, Arisaig and Moidart*	*8 arched concrete viaduct, 45.7 m span each arch*

Region	Structure Type	Cat	Date	Address	Comments
Highland continued	*Road bridge*	*C*	*1925-26*	*Loch Alvie Bridge on B1952*	*2 arched RC modern movement bridge (similar to Crubenmore Bridge)*
	Rail viaduct	*B*	*1901*	*Polnish, Arnbol, viaduct over Arnbol Burn*	*6 arched concrete viaduct*
	Dam	*B*	*1934*	*Loch Lagan Hydro Electric Dam*	*Concrete west face, topped by road on 24 arches*
	Dam	*B*	*1909*	*Dam for Kinlochleven water supply, Lismore*	*Mass concrete gravity dam*
	Causeway	*B*	*Late 19th century*	*South Erradale Causeway over River Erradale, Gairloch*	*14 arched rubble and cast concrete arch rings*
	Harbour	*B*	*Late 19th century*	*Inverfarigaig Pier, Boleskin and Abertarff*	*Pier extended in concrete*
	Harbour	*B*	*1904*	*Avoch Village harbour*	*Concrete C-plan pier partly covering original work*
	Harbour	*A*	*Early 20th century*	*Cromarty harbour*	*Later additions by Admiralty include extension to breakwater in RC*
	Lighthouse	*B*	*1905*	*Wick Harbour Lighthouses*	*Octagonal mass concrete tower*
	Lighthouse	*B*	*1880*	*Light tower, Arisaig Harbour*	*Concrete light tower, listed with harbour*
	Gravestone	*NL*	*1912*	*Gaelic Chapel Kirkyard, Cromarty*	*Several precast concrete military gravestones (Royal Navy)*
Midlothian	*Building*	*B*	*1875*	*Loanhead, former Reformed Presbyterian Church, Fountain Place*	*Walls droved concrete blockwork with concrete dressings and mouldings, cement render finish*
	Building	*B*	*1906*	*10 and 12 High St, Dalkeith*	*Floors constructed of steel girders, beams and concrete*
	Bridge	*B*	*1930*	*Braidwood Bridge over South Esk*	*Single span RC arch*
Moray	*Water tower*	*B*	*1898-1901*	*Garmouth, School Brae*	*One of earliest RC structures*
	Lighthouse	*B*	*1874-80*	*Buckie Harbour*	*Tall circular mass concrete light tower at end of east pier*
	Lighthouse	*C*	*1878*	*Buckie Harbour North pier lighthouse*	*Low 6-storey circular painted tapering to projecting concrete balcony*
	Lighthouse	*C*	*1878*	*Buckie Harbour, Cliff Terrace, Leading Light*	*Metal light on stepped concrete circular base*
	Lighthouse	*B*	*19th century*	*Burghead, Harbour North pier*	*Small whitewashed concrete beacon at end of pier*
	Lighthouse	*NL*	*c1891*	*Findochty harbour*	*Short cylindrical concrete tower on mass concrete base*
	Harbour	*B*	*1878*	*Buckie harbour*	*Long continuous concrete pier. First large concrete harbour in Scotland*
	Building	*C*	*1900*	*27 Seafield St, Portknockie*	*3 bay house, concrete dressings, concrete copes*
	Building	*C*	*1915*	*20 New Street, Findochty*	*2 storey, 3 bay house, painted concrete dressings, concrete copes to stacks*
	Building	*NL*	*1876*	*Garmouth, Durris cottage, Station Road*	*Single storey, shuttered concrete cement rendered and painted finish*
	Building	*NL*	*1876*	*Garmouth, The Old Schoolhouse, School Brae*	*2 storey house shuttered mass concrete, cement rendered and painted*
	Building	*NL*	*Late 19th century*	*Kingston-on-Spey, Cottage/ shed, Beach Road*	*Single storey shuttered mass concrete, cement roughcast*
	Building	*NL*	*Early 20th century*	*Kingston-on-Spey, Rowans Cottage Beach Road, outbuildings/workshop*	*Single storey, shuttered mass concrete cement render and roughcast finish*
	Building	*NL*	*Early 20th century*	*Former carter's cottage Mill of Towie, Botrphnie*	*Whitewashed concrete cottage*
	Building	*NL*	*Late 19th century-early 20th century*	*Newton farm Nr Garmouth*	*Large byre, base exposed shuttered concrete, modern metal sheeting above*

Region	Structure Type	Cat	Date	Address	Comments
Moray continued	*Building*	*A*	*1830*	*Tugnet Ice House, Tugnet*	*3 long turf-roofed vaulted chambers, mainly stone but east chamber upper walls shuttered concrete*
	Building	*A*	*Late 19th century*	*Knockando Woolmill*	*Weaving shed: concrete wall with brick repairs*
Perth and Kinross	*Power Station*	*B*	*1921*	*Hydro-electric power Station, Stanley Mills, Auchtergaven*	*Concrete lade, dam, weir, circular mass concrete turbine house*
	Rail viaduct	*B*	*1902-04*	*Allt an Fhionn, Comrie*	*5 span segmental arches, curved in plan, channelled mass concrete*
	Bridge	*B*	*1926-28*	*Dalnamein Bridge on Former A9 Blair Atholl*	*Single span RC, concrete parapet, Concrete block abutments*
	Building	*B*	*Late 19th century*	*The Knapp Rossie, Estate sawmill stable*	*2 storey rectangular plan stable, concrete frame, vertically timber boarded walls*
	Building	*C*	*1915*	*The Knapp Rossie, Estate sawmill seasoning shed*	*Concrete-frame shed*
	Building	*B*	*1912*	*The Knapp Rossie Estate sawmill,*	*Concrete launder trough on West elevation*
	Building	*B*	*1872*	*1 (Chapel Cottage), 2, 3 and 4 Parkview Terrace The Knapp, Longforgan*	*Shuttered concrete walls cement rendered finish. Outbuildings also shuttered concrete (formerly part of Rossie estate)*
	Building	*C*	*Late 19th century*	*The Old Schoolhouse, Parkview terrace, The Knapp*	*Single storey, shuttered concrete walls Formerly part of Rossie estate*
	Building	*NL*	*c1880*	*Glenshee Lodge, Glenshee*	*Mansion house/hunting lodge, shuttered mass concrete, smooth render finish*
	Building	*C*	*1896*	*Stable, Little Ballo farm, Longforgan*	*Shuttered concrete, cement rendered*
	Building	*B*	*Late 19th century*	*Marywell Farm, Longforgan*	*Concrete outbuilding*
	Building	*B*	*Late 19th century*	*Millhill Farm steading, Longforgan*	*Concrete walled bays to East range*
	Building	*C*	*1884*	*Snaigow Farm steading, Caputh*	*Shuttered concrete, concrete incorporated well-roundedriver aggregate with large boulders or packing stones*
	Building	*A*	*1825*	*Kinfauns Castle*	*Reported use of mass concrete foundations (Historic Scotland TAN 6)*
	Building	*B*	*1937-39*	*14 Wellmeadow, Blairgowrie*	*Former bank building, some channelled and reinforced concrete*
	Building	*A and B*	*1941*	*Cultybraggan Camp, Comrie*	*Various buildings brick and shuttered concrete*
	Building	*C*	*c1940*	*Findo Gask RN Airfield Control Tower*	*Brick and cellular concrete*
Shetland	*Building*	*NL*	*c1905*	*92 St Olaf Street, Lerwick*	*3 storey building, built as flats, shuttered mass concrete with cement render finish painted*
	Building	*B*	*Early 20th century*	*Lunna House Nesting, East mainland*	*Shuttered mass concrete extension to early 17th and 18th century building*
	Building	*C*	*Early 20th century*	*Manor House, Burravoe, Yell*	*Shuttered mass concrete to 1860s building*
	Building	*C*	*Early 20th century*	*Moarfield Mill, Cullivoe, Yell*	*Late 19th century watermill extended and raised in concrete early 20th century*
	Building	*C*	*C1900*	*Parkhill, Bixter*	*2 storey house shuttered mass concrete, cement render finish*
	Building	*C*	*1886*	*St Olaf's (North Yell) Kirk, Yell*	*1832 church remodelled c 1886 in shuttered concrete, cement render finish*
	Building	*C*	*1880*	*Windhouse, Yell*	*1707 house remodelled and extended in c1880 in shuttered concrete*
	Building	*C*	*1901*	*Leagarth House, Fetlar*	*2 storey house, mass concrete construction, concrete ridge stacks*
	Building	*NL*	*1900-25*	*Fishermen's cottages, Hamnavoe, West Burra*	*Several rows of single storey cottages wholly or partly shuttered mass concrete*

Region	Structure Type	Cat	Date	Address	Comments
Shetland continued	*Building*	*B*	*1891*	*Fair Isle, Head of Tind lighthouse and outbuildings*	*E buildings and tower harled and painted brick and concrete. 1941 accommodation block concrete dressings*
	Building	*B*	*1880*	*Gardie Cottage outbuilding, Bressay*	*Mass concrete extension c1880*
	Building	*C*	*c1900*	*Bixter, Park Hall*	*Poured concrete construction*
	Lighthouse	*C*	*1909*	*Mossbank lighthouse, Delting*	*Metal tower on concrete plinth*
	Lighthouse	*B*	*1858 and 1905*	*Bressay Lighthouse and keeper's accommodation*	*Tower on circular concrete plinth. Keeper's accommodation later concrete roofed porches. Engine CI tanks on concrete bases*
	Breakwater	*B*	*1915*	*2 Church Lane Lifeboat Station*	*Concrete breakwater*
South Ayrshire	*Harbour*	*B*	*19th century*	*Ayr Harbour*	*Harbour walls mass concrete quays*
South Lanarkshire	*Bridge*	*B*	*1898-1904*	*Larkhall Viaduct over Avon Water*	*Concrete foundations to piers*
	Building	*B*	*1921*	*24 Woodside Walk, Mcarthur's Woolen Mill, Hamilton*	*RC frame building*
Stirling	*Aqueduct*	*C*	*1887*	*Tom-an-eas aqueduct bridge over Duchray Water, Aberfoyle*	*Single span mass concrete faced with granite*
	Aqueduct	*A*	*1856-59*	*Loch Katrine, Royal Cottage aqueduct intakes*	*Retaining wall projecting into loch, possibly mass concrete core sandstone faced*
	Aqueduct	*A*	*1860-64*	*Couligarten aqueduct bridge no 2, Duchray valley*	*Concrete central pier*
	Rail viaduct	*A*	*1885-86*	*Killin, Viaduct over River Dochart (Kinnell Estate)*	*Second oldest mass-concrete viaduct in Britain (after Falls of Cruachan)*
	Rail viaduct	*B*	*1902-04*	*Viaduct over Ogle Burn, Comrie*	*9 arched viaduct.*
	Dam	*A*	*1910-15*	*Loch Arklet Dam*	*350 yd dam concrete faced with sandstone*
West Dunbartonshire	*Canal basin*	*B*	*1896*	*Bowling, Upper canal basin and Lock*	*Mass concrete walls*
	Building	*C*	*1930*	*205-209 (odd) Overtoun Terrace, Glasgow Road, Dumbarton*	*3 storey, 21 bay tenements. Cream concrete designed to appear as sandstone*

Notes on Table 1

While there are 263 sites identified in Table 1 this does not represent the total number of historic concrete buildings and structures listed. This is because a single reference does not necessarily denote one structure or building on its own. Examples of this are at Crail Airfield in Fife and the former prisoner-of-war camp at Cultybraggan, Comrie, where multiple structures are combined in a single citation. Other examples include rows of terraced houses, complete tenement blocks, groups of agricultural buildings and industrial sites containing a number of separate buildings but given as a single listing. The use of single listing may also include a number of separate buildings that are often in different ownership, and this can be an important consideration in the context of conservation and repair. At the same time there are some sites containing numerous similar but separate buildings where each building is given a single citation. The use of a single citation in Table 1 does therefore not accurately reflect the total number of individual concrete buildings in Scotland.

A further reason that Table 1 does not represent a complete record of the early use of concrete in Scotland is that many buildings have yet to be identified. For example, many listing descriptions record the external finish to the building as 'rendered' or 'harled' where it has not been possible to identify the underlying wall construction. In addition, there are many concrete buildings, especially those with rendered finishes, which will remain undetected until repairs or alterations are carried out. This also includes buildings and structures where the main support is provided by a concrete core, with a thin masonry external facing. Additionally, some buildings may have significant concrete elements which have not been identified or highlighted, such as the vaulted roof in the 1886 St Sophia's Church in Galston which is an important early example of reinforced concrete.

Analysis of early concrete structures throughout in Scotland

Analysis of all the 263 early concrete structures so far identified in Scotland (Table 1) tends to confirm the known concentration of concrete structures in particular areas (Table 2). Highland has the largest number (30%), followed by Aberdeenshire (10%), with Moray and Perth and Kinross (each approximately 7%) also significant. Other concentrations occur in Dundee, Shetland and Glasgow; with Glasgow having a high proportion of early reinforced concrete structures.

Region	Structure Type									
Council Area	Domestic	Agriculture	Industrial	Other	Harbour	Lighthouse	Bridge & Viaduct	Dam	Total	
%										
Aberdeen	1	0	2	7	0	2	0	0	12	4.5
Aberdeenshire	9	1	1	3	3	4	5	0	26	9.8
Argyll and Bute	0	2	0	1	0	1	1	0	5	1.9
Borders	1	0	0	2	0	0	0	0	3	1.1
Clackmannanshire	1	0	2	0	0	0	0	0	3	1.1
Dumfries and Galloway	0	1	1	0	0	1	1	0	4	1.5
Dundee	8	0	4	1	4	0	0	0	17	6.4
East Ayrshire	0	0	0	1	0	0	0	0	1	0.4
East Lothian	2	0	0	0	1	0	1	0	4	1.5
Edinburgh	3	0	1	3	2	0	1	0	10	3.8
Falkirk	1	0	0	0	2	0	0	0	3	1.1
Fife	0	0	0	7	2	1	2	0	12	4.5
Glasgow	1	0	7	8	0	0	4	0	20	7.6
Highland	31	7	2	14	3	2	18	2	79	29.6
Midlothian	1	0	0	1	0	0	1	0	3	1.1
Moray	8	2	1	2	1	4	0	0	18	6.8
Perth and Kinross	4	7	2	2	0	0	2	0	17	6.8
Shetland	9	2	0	1	1	2	0	0	15	5.7
South Ayrshire	0	0	0	0	1	0	0	0	1	0.4
South Lanarkshire	0	0	1	0	0	0	1	0	2	0.8
Stirling	0	0	0	2	0	0	3	1	6	2.2
W Dumbartonshire	1	0	0	1	0	0	0	0	2	0.8
TOTALS	81	22	24	56	20	17	40	3	263	100
%	31	8	9	21	8	7	15	1	100	

Table 2 Distribution of known concrete buildings within Scotland. Note: Domestic includes rows of terraces and other groupings (e.g. tenements) as one listing; Agricultural and industrial buildings can include groups of buildings containing concrete elements.

Further analysis of the data in Tables 1 and 2 shows the distribution of mass concrete compared to other concrete structures (Fig A1).

Analysis of the type (i.e. function of concrete structures listed) indicates that domestic buildings (essentially mass concrete) form the largest group at 31%, although combined engineering related structures (harbours, lighthouses, bridges and dams) are also significant (Fig A2).

Fig A3 shows that the majority of buildings incorporating early concrete were built between 1850 and 1920, with the peak occurring in the period 1880 to 1919.

Data for the number of recorded reinforced concrete structures show that, as expected, there is a steady increase in its use after c.1920 (Fig A4), although it should be noted that these figures relate only to listed buildings .

Further information on early-patented reinforced concrete buildings in Scotland is contained in Borden (2010) where 70 buildings, dating from 1904 to 1921, are identified.

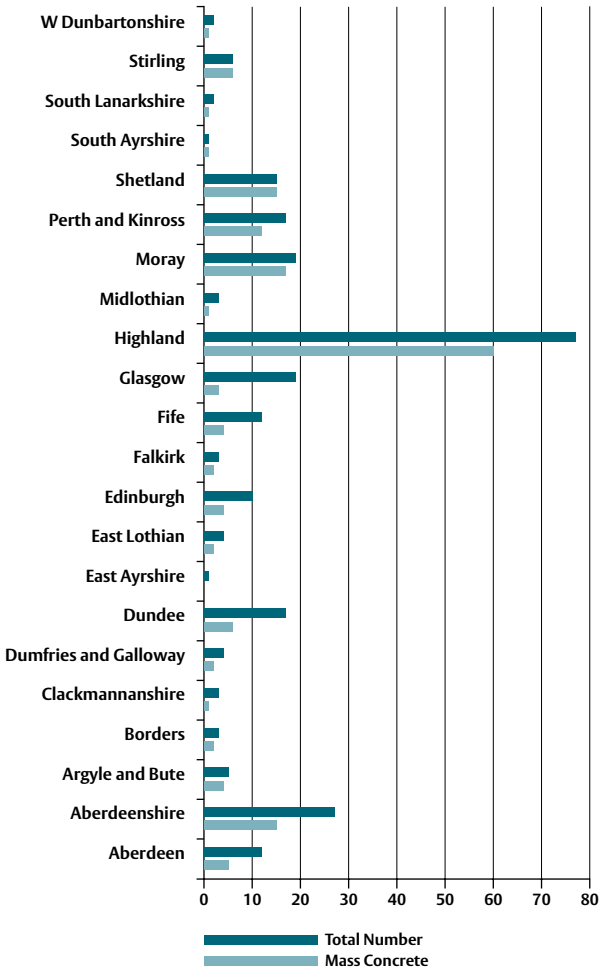

Fig A1 Distribution of concrete buildings (total and mass concrete).

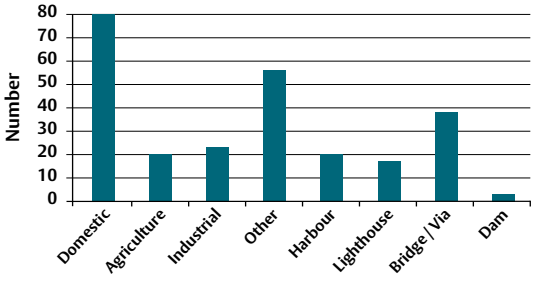

Fig A2 Concrete buildings/structures by type or function.

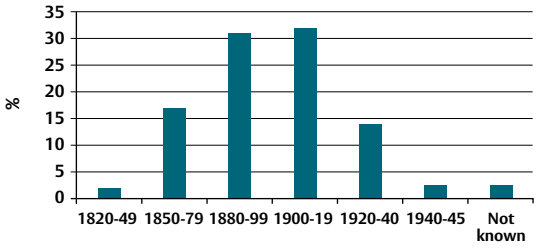

Fig A3 Distribution of age (date of construction) for concrete buildings and structures in Table 1 between 1820 and 1945.

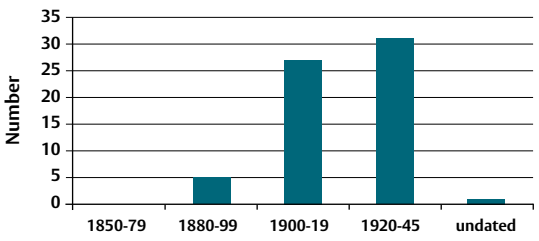

Fig A4 The date of construction of reinforced concrete structures from Table 1.

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