Historic concrete structures in New Zealand

Overview, maintenance and management

Peter Reed, Kate Schoonees and Jeremy Salmond

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ABSTRACT

Early concrete structures form an important part of New Zealanders' cultural heritage. This handbook describes the historical development of concrete and its properties, and outlines the background to early concrete structures, concentrating on the early use of concrete (up to the 1940s) as a building material in New Zealand. It identifies characteristic defects and patterns of deterioration in the material, and explains how these may be recognised and described. Concrete is a complex and varied material, and its production has become more sophisticated over time; thus, its manufacture, properties and uses were influenced by the knowledge and perceptions at the time of construction. Repair methods have also changed considerably in the last few decades and are still changing. As the components of concrete have been undergoing continuous development over the past 150 years, architects and engineers involved in the preservation of historic concrete structures need to understand the material of the period and the manner of its making and use. Therefore, a set of evaluation procedures and conservation strategies for the preservation and repair of these structures is proposed. This handbook is intended to assist those lay persons who have responsibility for administration of historic resources or whose duties involve making decisions about their care and maintenance.

Keywords: concrete technology, historic concrete, natural cement, Portland cement, hydraulic lime, pozzolans, plain concrete, reinforced concrete, defects, deterioration, repair, conservation

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1. History of concrete

1.1 ORIGINS AND DEVELOPMENT OF CONCRETE

The Romans are well known for their extensive use of concrete more than two millennia ago, yet experience and knowledge of *cement*[1] materials is still developing and expanding. Scientific research into cement and concrete technology surged dramatically from the beginning of the 20th century with the growing use of steel-reinforced concrete, but even today, almost 180 years after the first patent for *Portland cement*, many gaps in our understanding remain. Concrete has been one of the most widely used building materials over the past 100 years. It has made possible numerous complex structures, ranging from bridges, monuments and buildings, to civil engineering works.

The earliest use of concrete dates back to before 5600 BC: a 250-mm floor slab from this period, which was made using a red lime, *sand* and gravel mix, has been discovered on the banks of the Danube in Yugoslavia. In Egypt, murals dating from 1950 BC show various stages of the process of making concrete (Stanley 1980). The first concrete used was mass or plain concrete, which exploited its great strength in compression. This was produced using limestone, which was burnt to form lime or *natural cement*. To make concrete that would set and harden, the lime had to have sufficiently high *hydraulic* properties; that is, the concrete had to be able to set in water or when exposed to only a small amount of air.

Hydraulic lime was obtained by using impure limestone that contained a significant amount of clay, or by the addition of naturally occurring volcanic ashes, or *pozzolans*, to ordinary lime. Both types of cement were very variable in their properties. The Romans used lime concrete extensively in their building works. Roman concrete was used principally as a filling in brick or stone masonry walls, into which the pozzolanic cement, made from lime and pozzolanic ash, was poured over layers of broken stone and rubble until the structure was filled.

During the Middle Ages, the use of concrete declined, although isolated instances of its use have been documented and some examples have survived. During this period, lime with low hydraulicity continued to be used for *mortar*, plastering and lime washing.

Concrete was more extensively used again during the Renaissance and its manufacture was described in a work by De Lorme, published in 1568 (Gwilt 1881). At this time, mass or plain concrete was used in structures such as bridge piers. Pozzolanic materials were added to the lime, as done by the Romans, to increase its hydraulic properties (Thornton 1996).

In the 18th century, with the advent of new technical innovations, a greater interest in concrete developed. In 1759, John Smeaton experimented with types of limestone collected from many parts of Britain. He discovered that lime that was made from limestone containing a significant proportion of

[1] See Glossary for definitions of technical terms (shown in italics).

clay would always produce a *hydraulic cement*. He decided to use blue lias, a moderately hydraulic lime, to which he added a pozzolanic material to achieve a very hard and hydraulic lime for the Eddystone lighthouse (Smeaton 1793: 181, cited in Swallow & Carrington 1995). This material was used in the base of the structure and in the bonding mortar of the masonry superstructure. (The lighthouse stood for 120 years until it became unsafe, due to the erosion of the rock on which it stood rather than any failure of the cement; Swallow & Carrington 1995.)

Smeaton's work was followed by Joseph Aspdin who, in 1824, patented the first 'Portland' cement, so-named because concrete made with the cement was similar in colour to Portland stone. In 1844, Aspdin's son James took over the business of producing cement, with the company bearing the family name until 1904. Although the American Obadiah Parker produced a very similar cement in the 1830s, for many years England was pre-eminent in producing and exporting Portland cement to the rest of the world, including India, Australia, New Zealand, South Africa, Canada and Russia. By the 1850s, English, French and German engineers were using Portland cement in docks, harbour walls and military structures.

In spite of these early engineering uses of the material, concrete did not develop as a general building material until the late 1800s. At first it was largely used as mass or plain concrete because of its inherent compressive strength. Artificial cements were then developed, in which carefully gauged proportions of limestone and clay were burnt to obtain specific properties. These concretes had much higher crushing strengths and lower porosities, as well as a greater degree of uniformity than the earlier hydraulic limes and natural cements.

The final advance was the development of reinforced concrete, which had greater tensile strength and was much more versatile for building and construction. The first experiments with reinforcing concrete, which used first wrought iron and later steel, started in the 1850s, although isolated earlier examples exist—for instance, the Pantheon in Rome (AD 125) is known to have bronze reinforcing in its dome; Christopher Wren used chains embedded in concrete to resist lateral thrust in the dome of St Paul's church in London, which was built between 1675 and 1710 (Jones 1913); and Thomas Telford used iron bars in the abutment of the Menai Straits bridge in 1826. Ralph Dodd took out one of the first patents on the use of wrought iron bars in concrete in 1818, and by 1850 numerous patents had been registered for combining iron with concrete.

A number of people experimented with iron mesh and rods in beams and slabs for buildings. Between 1870 and 1877, the American Thaddeus Hyatt was one of the first to realise the importance of anchoring the ends of the reinforcing rods, which he fitted with nuts and washers to prevent them from pulling out of the concrete. Hyatt used an elaborate lattice of flat iron bars with holes at intervals for transverse round bars in an attempt to increase the tensile strength of concrete slabs and beams (Fig. 1). He registered numerous patents, but never made a commercial success of his work (Jones 1913).

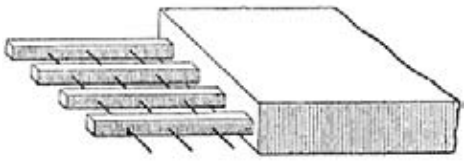

Figure 1. Hyatt system, applied at first to floor slabs and later also to beams (from Marsh 1905).

The principle of reinforcing concrete for general use was established in the late 1800s. Terms to describe this material included béton armé, armoured concrete, ferro-concrete (commonly used in New Zealand), and concrete steel. The term 'reinforced concrete' only came into general use later (Marsh 1905).

In 1892, François Hennebique, who is regarded as the French pioneer of concrete, patented a system of steel-reinforced beams, slabs and columns. Hennebique's patent proved to be one of the most popular and was used for a large number of structures built in England between 1897 and 1919, including buildings, bridges, viaducts, maritime structures, reservoirs, water towers and canal works. In Hennebique's system (Figs 2 & 3), steel reinforcement

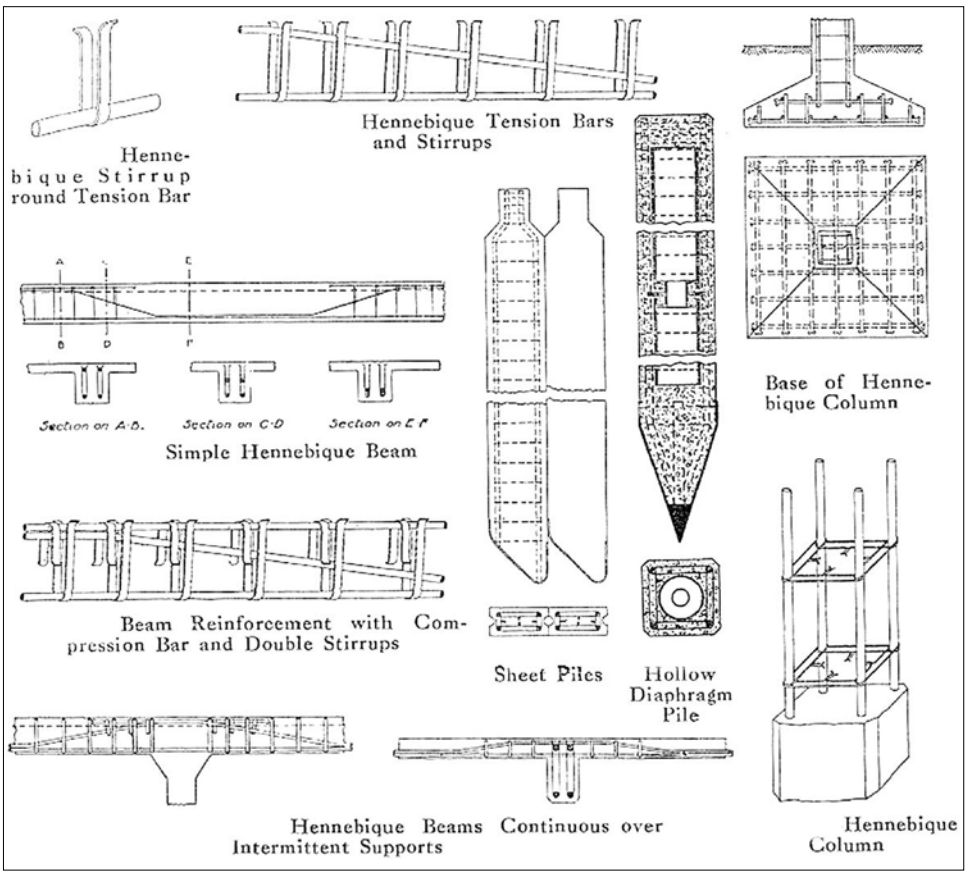

Figure 2. Hennebique system, showing general arrangement of reinforcement in beams (from Jones 1913).

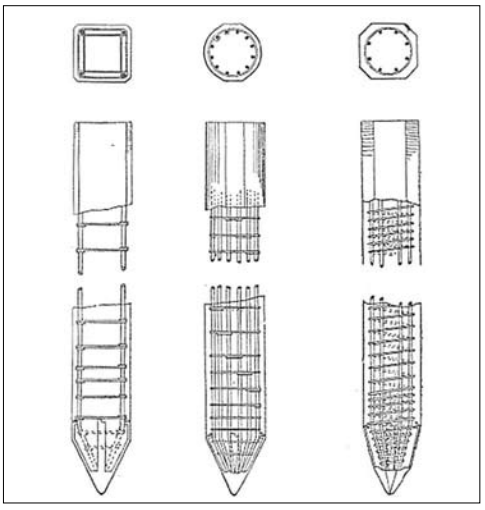

Figure 3. Types of early pile, from left to right: Hennebique square pile, Coignet round pile, Considère octagonal pile (from Marsh 1905).

was placed correctly in the tension zone of the concrete; this was backed by a theoretical understanding of the tensile and compressive forces, which was developed by Cottançin in France in 1892.

Ernest Leslie Ransome patented a number of improvements to reinforced construction, including expansion joints and the use of twisted bars to improve bonding (Figs 4 & 5). He built the first reinforced concrete bridge in the USA in 1889, and a number of warehouses and factories (Jones 1913). The elegance of Ransome's structures (Fig. 6) and their repetitive symmetry were much admired by later European architects (Thornton 1996).

Auguste Perret was another Frenchman who had a great impact on the use of concrete. In his church Nôtre Dame du Raincy he used tall, round, tapering columns with vaulted slabs and large areas of glazed, non-load-bearing walls. Gustav Maillart, a Swiss designer and pupil of Hennebique, developed the mushroom column and flat slab, and is noted for his elegant and adventurous bridges. Pier Luigi Nervi experimented widely with the possibilities that reinforced and precast concrete offered, and particularly applied these techniques to the construction of domed structures.

By the 1900s, concrete was generally used in conjunction with some form of reinforcement, and steel began to replace wrought iron as the predominant tensile material. A significant advance in the development of reinforced concrete was the pre-stressing of the steel reinforcing. The

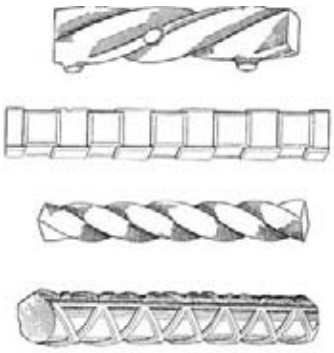

Figure 4. Examples of early steel bars designed to improve the bond between concrete and steel (from Kidder 1909).

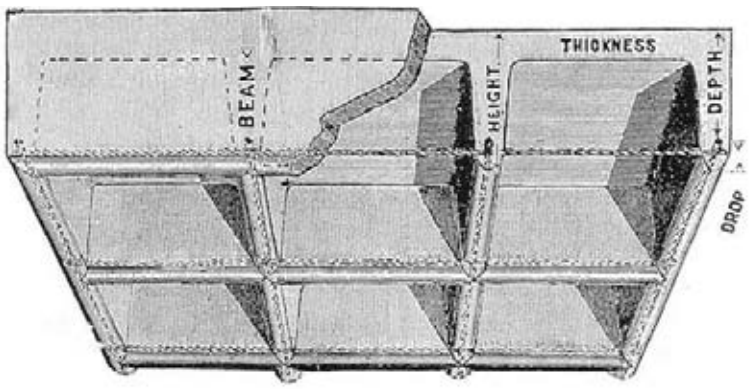

Figure 5. Ransome's system, which was widely used in the USA in the early 1900s, was similar to the Hennebique system, except for the use of square twisted reinforcing bars (from Marsh 1905).

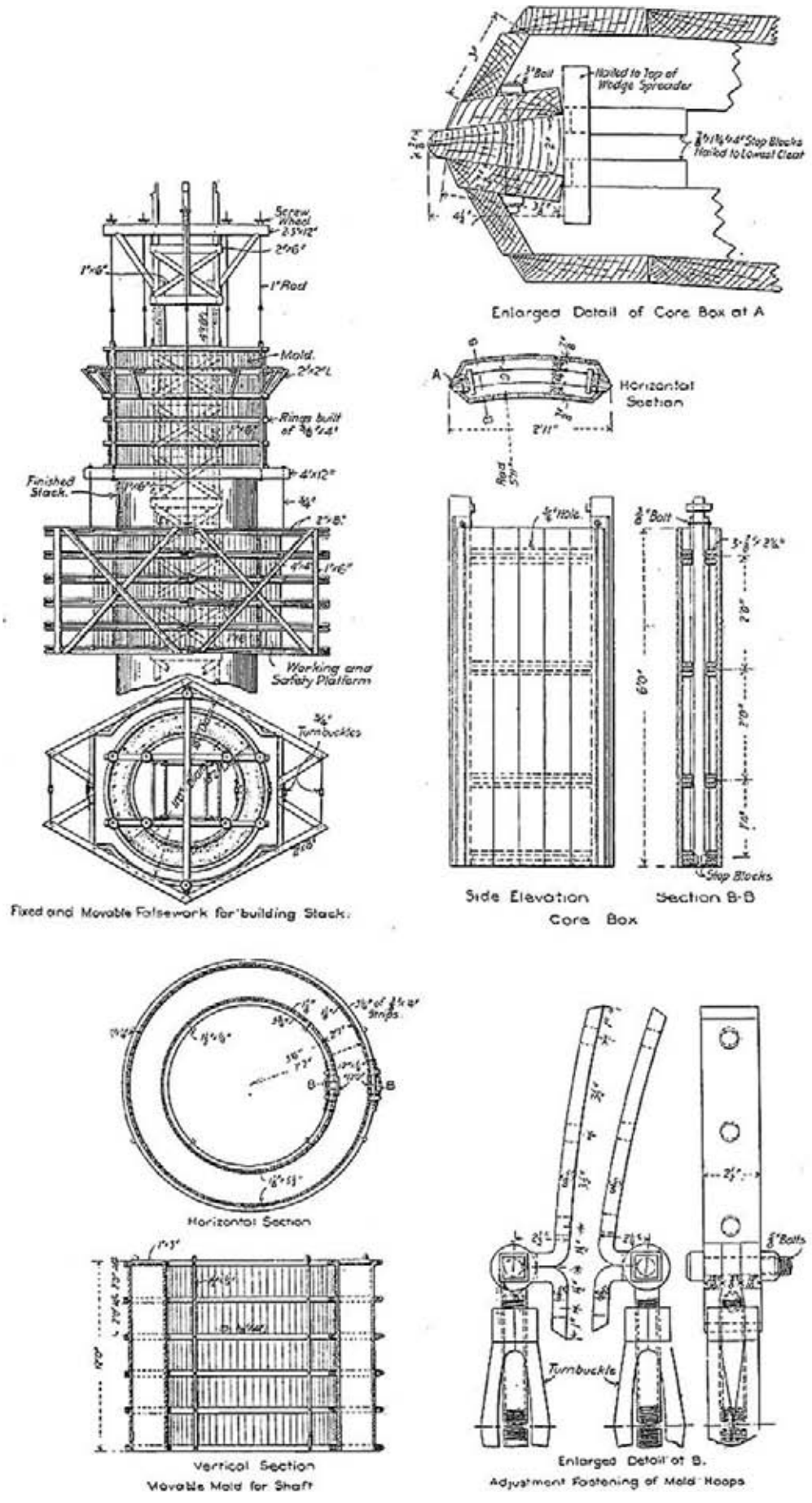

Figure 6. Shuttering and moulds used by Ransome's in 1903 for a reinforced chimney 165 feet high (from Marsh 1905).

earliest experiments date from 1886, when C.E. Dochring, a German builder, pre-tensioned iron wires. These experiments were unsuccessful, as high-tensile steel was not used and the concrete was not of a high enough grade for this type of construction. Further experiments in pre-stressed concrete were undertaken in the 1920s by Eugene Freyssinet, but the technique was not widely used until the 1940s. However, in 1929 the New Zealand Public Works Department used pre-tensioned No.8 wires in concrete fence posts (Thornton 1996). This was one of the earliest practical uses of what was essentially a form of pre-stressed concrete.

Reinforced concrete was generally cast *in situ* and this is still a widespread practice. However, in modern construction, precast concrete is widely used, to reduce construction times and to ensure greater accuracy and strength of concrete components.

1.2 USE OF CONCRETE IN NEW ZEALAND

Although New Zealand was relatively isolated in the late 1800s, a surprising amount of this newly developing technology was used here. Records show that casks of artificial cement were imported from England as early as 1843[2], and numerous concrete structures were built between 1840 and 1900, including many engineering and military structures, the scale and size of which increased with time. Private citizens and farmers built a large number of experimental buildings and structures, including settler houses and farm buildings. A wide range of lime, cement and aggregate was used, depending on what was available.

As occurred in Britain and the rest of Europe, the first use of concrete in New Zealand was predominantly in the form of plain or mass concrete, although a few isolated experimental attempts at reinforcing were undertaken from the 1870s. After 1900, New Zealanders embraced the use of reinforced concrete with enthusiasm. While Britain had strict building regulations and established masonry construction methods that stifled the use of concrete and resisted the changes brought by the new techniques, this was not the case in newly developing New Zealand.

There are probably several reasons for the wide use in New Zealand of what was, at that time, still an experimental building material: the rapidly growing country had urgent need of infrastructure; concrete was found to be a robust structural material comparable to both steel and timber; it could be constructed using a wide range of 'as-found' materials; there was a shortage of skilled tradesmen such as stonemasons and bricklayers, and concrete required less skilled labour; and it proved more durable and cost effective than either steel or timber in the often damp, humid environment. Early settlers seemed ready to experiment with new possibilities in this new environment, and concrete offered ways of making buildings fireproof and later, with reinforced concrete, earthquake resistant. Although timber was

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[2] Thornton (1996) noted that the records did not specify whether imported cement was 'Roman' or 'Portland' cement. However, in 1843 Portland cement was not commonly used in England, whereas Roman cement was being produced in large quantities.

very widely used in the early colony, it was nevertheless not regarded as offering the sense of durability of traditional masonry, whereas concrete provided that sense of robust permanence.

Thornton (1996) described the wide and varied use of concrete in New Zealand between 1850 and 1939, highlighting many structures that were unique even in world terms. Thornton (1996) provided several examples of early concrete structures from the 1850s and '60s, including:

- A concrete cottage described in the Lyttleton Times 17 April 1852.
- The bridge piers and abutments of a bridge outside New Plymouth in 1859.
- The 1867 bridge over the Waiwakaiho River, built with concrete piers; the bridge was replaced by a reinforced concrete structure in 1907.
- A two-storey mass concrete house near Mosgiel, built in 1862 by John Gow, an early settler and farmer. Even by international standards, this is remarkable for its age and construction materials.

During the 1870s, numerous concrete structures were built in New Zealand, including the Oamaru breakwater, which was constructed of concrete blocks, each weighing 25 tons, and the shaft of the valve tower of the Karori reservoir, which was built in concrete in 1873 and is beautifully detailed with scrolled corbels to support the timber upper structure. Many large residences and farmhouses were also built using mass lime concrete.

The first attempts to use reinforcing in New Zealand were made in the 1870s, but the first real use of reinforcing is documented as the 18-m-high water tower at the New Zealand Railways workshops in Addington, Christchurch, which was built in 1883 and reinforced with tons of scrap steel; this was still recently in use (Thornton 1996).

From the 1880s onwards, the type and variety of concrete structures increased (Thornton 1996). Concrete was used in every form of building construction, including coastal fortifications; engineering structures, such as graving docks, lighthouses, bridge piers and water towers; factory and farm buildings; residential buildings; and public buildings, such as health facilities, schools, banks and religious buildings. Both lime and Portland cement concretes were used, still largely in the form of mass concrete. Until this time, almost all of the artificial cement used was imported, but this now started to change very gradually as lime and cement industries were established on a commercial scale.

The first concrete lighthouse in the world was built in 1873 in Jersey in the Channel Islands. New Zealand followed within a decade, constructing a concrete lighthouse on Burgess Island in the Hauraki Gulf in 1882. This was built using purpose-made concrete blocks that had to be winched to the summit, making it a pioneering use of precast concrete in this country.

The former Congregational church of St James in Beresford Street is a very early concrete construction that was built in 1876 and is still in use. In 1884, the former synagogue in Princes Street, Auckland, was built of mass concrete, using Roche lime produced locally near Warkworth. The mass concrete was then rendered internally and externally, a common finish for concrete buildings at the time. Recently restored and now used by the

University of Auckland, the building is in excellent condition. Many Catholic churches designed by the noted engineer/architect Frank Petre incorporated concrete in their construction, in some cases reinforced. His basilica church of St Patrick in Oamaru (1894) and Sacred Heart Cathedral in Wellington (1895) (Fig. 7) used mass concrete walls faced in Oamaru stone—the latter with hoop iron reinforcing. Petre's fondness for the material earned him the nickname 'Concrete' Petre.

Concrete was widely used in coastal military defence structures during the Russian war scare of the 1880s. For example, Fort Takapuna (formerly Fort Caughley) has 600-mm-thick concrete retaining walls and a roof structure poured over railway irons (Figs 8 & 9). Similar designs were used in fortifications across the country.

Thornton (1996) documented the increasingly varied use of concrete in the 1890s. Mining structures such as the Crown Mine Battery at Karangahake (today an industrial monument) were built during this time, and its ruins exhibit massive concrete ramparts and impressive stone walling. Concrete also proved very useful in developing infrastructure and transport systems across the country, as in the Kohatu railway tunnel, which was built in 1893 using precast concrete blocks.

Reinforced concrete came into common use in New Zealand from the 1900s onwards, its use stimulated by the risk of earthquakes. Larger and more substantial engineering works, buildings and structures were now built of this composite material, with the increased tensile strength making it much more adaptable. Not only bridge piers but entire bridges could now be built in reinforced concrete. Reinforced concrete dams in New Zealand predate those in England, where masonry was the preferred material. Between 1904 and 1908, a dam was constructed of mass concrete in Nelson. However, this was still experimental, and it had many problems with leaking and its height had to be reduced. Ferro-concrete was also used in some of the first State houses to be built in 1905. Two of these still stand today in Patrick Street, Petone (Thornton 1996), which is now a conservation area.

Figure 7. Sacred Heart Cathedral, Wellington. Conventional stone and brick masonry, with a core of reinforced concrete.

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