

STUDIES IN THE HISTORY
OF CIVIL ENGINEERING

Volume 11

Early Reinforced Concrete

Frank Newby



Studies in the History of Civil Engineering

Volume 11

Early Reinforced Concrete

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General Editor: Joyce Brown

*with the assistance of M.M. Chrimes, A.W. Skempton,
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edited by
Frank Newby

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Contents

Acknowledgements	vii–ix
General Editor’s Preface	xi–xii
Introduction	xiii–xxxv
1 Sir Robert Smirke: a pioneer of concrete construction <i>J. Mordaunt Crook</i>	1
2 Concrete and the structural use of cements in England before 1890 <i>B.L. Hurst</i>	21
3 W.B. Wilkinson (1819–1902) and his place in the history of reinforced concrete <i>Joyce M. Brown</i>	43
4 Portland cements, 1843–1887 <i>A.W. Skempton</i>	61
5 The emergence of reinforced concrete, 1750–1910 <i>John W. de Courcy</i>	97
6 The origins of reinforced concrete <i>Cyrille Simonnet</i>	119
7 Hennebique and building in reinforced concrete around 1900 <i>Gwenaël Delhumeau</i>	135
8 Agents of change: Hennebique, Mouchel and ferro-concrete in Britain, 1897–1908 <i>Patricia Cusack</i>	155
9 The remarkable structures of Paul Cottancin <i>G.J. Edgell</i>	169
10 The era of the proprietary reinforcing systems <i>M.N. Bussell</i>	187
11 Architects and the reinforced concrete specialist in Britain, 1905–1908 <i>Patricia Cusack</i>	217
12 Genesis of reinforced concrete construction <i>W.K. Hatt</i>	231

13	The Ward House: a pioneer structure of reinforced concrete <i>Ellen W. Kramer and Aly A. Raafat</i>	251
14	The first reinforced-concrete skyscraper: the Ingalls Building in Cincinnati and its place in structural history <i>Carl W. Condit</i>	255
15	The consulting engineer and early concrete bridges in California <i>John Snyder and Steve Mikesell</i>	293
16	Early reinforced concrete structures in New South Wales, 1895–1915 <i>D.J. Fraser</i>	309
	Index	337

PUBLISHER'S NOTE

As this book was going to press, the General Editor and Publishers learned with deep regret of the death of Frank Newby. It is a sad duty to present this work following his death and it is especially sad that Frank Newby did not see this work in print, although he committed much time to its careful completion just prior to his death.

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General Editor's Preface

Joyce Brown

Civil engineering has a long history. Although practitioners did not begin to describe themselves as 'civil engineers' until the eighteenth century, the origins of their work lie in the construction skills of the ancient world and in the works of military engineers. Shortly after British civil engineers had formed themselves into a professional body, the Institution of Civil Engineers in London, their role was described in 1828 by Thomas Tredgold in these words:

Civil engineering is the art of directing the great sources of power in Nature for the use and convenience of man.¹

He thus neatly encapsulated what the civil engineer's job is about – the provision of the means to give society what it wants for its survival.

As time has gone by, the civil engineer's skills have had to diffuse over an ever-widening field and at the same time become more specialised. In all periods he has had to be the ingenious 'fixer', but more than a mere artisan – a point observed in the Institution's motto, *scientia et ingenio*.

The history of civil engineering is a fascinating one. Certainly 'the great sources of power in Nature' are not always directed without a certain amount of opposition by them, and the provision of the basic requirements – habitation, water supply, main drainage, harbours, bridges, places of worship, transport systems by land and water – has called for inventiveness and sometimes for daring and courage.

Yet interest in the history of civil engineering is not of long standing, and it seems fair to state that most of the important work has been done in the last forty years. With a few notable exceptions, most of the major books on the subject have appeared in that era; many specialist societies with their own transactions have been founded; and many of the journals in which articles might be published have come into existence. While archaeologists and architectural historians have long made their contribution to this subject, their ranks have been swelled by a large number of serious scholars – including engineers themselves – now interested in recording and evaluating the engineering achievements of earlier times. In particular, there is a lively interest in the study of our industrial past, at least in part because some of the evidences of it are already disappearing from the landscape.

Our intention in creating the series of which this volume forms part is to provide, through the reproduction of important contributions to this subject, an

¹ *Minutes of Council, Institution of Civil Engineers*, 4 January 1828.

invaluable reference collection for its study. The series encompasses many different branches of engineering from early times to the beginning of the twentieth century; its perspective is global; and the chosen articles have an international authorship, to the extent that this can be achieved for an essentially English-language series. The introduction to each volume has allowed the volume editor to set the pages selected in the context of the whole history of the subject and its historiography, while the provision of references and a bibliography will enable the reader to go further into the study of the topic.

This series will have succeeded if it gives civil engineers some unexpected insights into their own craft and other readers a new way of looking at engineering structures.

The volume editors were chosen for their particular knowledge and expertise in the field. They have worked with enthusiasm and good will to put together collections of articles intended to be both informative and stimulating, and I am grateful to them for their efforts. Where possible, they have incorporated the work of the best scholars, while at the same time giving preference to articles often obscurely published and not readily available. The learned journals are represented, as also are conference proceedings and essay chapters contributed to books.

In all of this, I have been much assisted by my Advisory Panel. Emeritus Professor Sir Alec Skempton (Imperial College) has made himself freely available to me for consultation on many aspects of this venture. Mike Chrimes (Librarian of the Institution of Civil Engineers), Dr. Norman Smith (Emeritus Reader, Imperial College) and James Sutherland (formerly a Senior Partner in Harris and Sutherland, London, consulting engineers) have all contributed valuable advice based on their extensive knowledge of particular fields. The idea for the series was developed in discussion with Dr John Smedley of Ashgate, and Publisher of the Variorum Collected Studies Series, who has given me much personal support and the benefit of his experience.

I am grateful also for the help given by the staff of several libraries, notably Kay Crooks and Susannah Parry in the library of the Department of Civil Engineering, Imperial College, and Mike Chrimes and staff of the library of the Institution of Civil Engineers, London. Many friends have given me encouragement and useful advice; in particular, I want to thank Paula Kahn and Mark Baldwin.

*Joyce Brown,
Formerly Department of Civil Engineering,
Imperial College, London*

Introduction

Frank Newby

Pier Luigi Nervi has described reinforced concrete as ‘the most fruitful and generous of all building materials’.¹ Over the last hundred years this remarkable man-made material has transformed the built environment, giving a new scale to architecture and civil engineering. It has a long and fascinating history, beginning with the use of mass concrete when the building industry came to terms with the idea that an initially wet mix of ingredients could slowly harden into a stone-like mass. The addition of metal reinforcement to provide tensile strength, which only occurred in the last quarter of the nineteenth century, produced a new structural material of greater versatility than wrought iron, steel or timber, which, like cast iron, could be moulded into a variety of shapes, but for the first time could also form a continuous monolithic structure of almost limitless size.

Sixteen papers have been selected for reproduction in this volume to give the reader a picture of the emergence of reinforced concrete as a new structural material. Some of the papers naturally overlap in subject while other aspects of reinforced concrete, such as the chemistry of cement, the control of materials and construction on site, or structural failure are not covered. However, it is hoped that the bibliography will supply a list of sources for further study.

Binders, Mortars and Concrete

Concrete is an agglomerate of sand and a coarse material such as gravel or crushed stone which, when mixed with water and a binder, slowly hardens in the atmosphere to form an artificial stone. The earliest binder to be widely used was lime, and concrete made with it is known as lime concrete; lime mortar is a mix of sand and lime and has been used for centuries of masonry construction. Lime concrete and mortar only gain strength slowly, a factor which influences the rate of building, but its great disadvantage is that it will not set under water.

This was the problem encountered by John Smeaton, engineer and scientist, when he was commissioned in January 1756 at the age of 32 to rebuild the Eddystone lighthouse. He had to have an hydraulic mortar, that is one which would set under water, to bind the foundation blocks together. He knew that some

¹ Nervi, *Structures*, 49. Nervi, engineer and contractor, was one of the greatest twentieth century designers in reinforced concrete. This is a translation of his 1955 book, *Construire Correttamente*, his most important publication, giving his views on the essential qualities of reinforced concrete obtained over many years of practical experience.

limes had hydraulic qualities and that the addition of Dutch tarass (or trass) to limes would render them hydraulic, so he carried out a series of simple tests on mortars with tarass and with different limes, using both fresh and sea water. He consulted the few available books on engineering and found in Belidor a reference to a statement by Vitruvius that pozzolana, a ground volcanic rock from Naples, also gave hydraulic qualities to lime.² It was widely used by the Romans from the first century BC, most spectacularly for the 43-metre diameter dome of the Pantheon in Rome in 128 AD.³ Fortunately, Smeaton was able to acquire a quantity of pozzolana and further tests showed him that it was a much better material than tarass. His great discovery was that lime made from Aberthaw limestone, which was already known to be hydraulic, had this property because of a significant clay content.⁴ He stopped short of analysing the clay chemically and it was left to Vicat to complete the explanation. The first stones of the lighthouse were bedded on 12th June 1757, some seventeen months after his appointment, but he did not publish details and results of his tests until 1791.⁵

In 1796 James Parker discovered that by calcining particular stones, found on the beaches of Kent and in chalk formations, and grinding the residue to powder, he was able to produce a natural hydraulic binder, which he named 'Roman cement'. Its only drawback was that it set very quickly and was therefore unsuitable for large volumes of concrete, but for mortar it was ideal and was widely used.

The next major step in the understanding of the nature of a binder or cement, as it became known, was carried out by the French engineer, L.J. Vicat, who published his first book on the subject in 1818.⁶ His second book of 1828 was translated into English in 1837 by Capt. J.T. Smith,⁷ who greatly added to the original in the light of his own experimental work, which also enabled him to explain and evaluate Vicat's conclusions. Smith comments in his preface that, 'It is not merely in the accuracy of the details of his valuable invention that M. Vicat has done the most service to the profession by the publication of his work [but] the variety of other processes which he has illustrated has increased the resources of the practical engineer in every situation'. Vicat's main contribution was to show that the presence of silica was essential to produce an hydraulic

² B.F. de Belidor, *Architecture hydraulique*, Vol. 2, part 2 (Paris, 1737–53), 86.

³ Rowland J. Mainstone, *Developments in Structural Form* (London, 1975), 115–18.

⁴ Norman Smith, 'Scientific Work', in A.W. Skempton (ed.), *John Smeaton FRS* (London, 1981), chapter 11, 54–7.

⁵ Smeaton, *A Narrative of the building...*, 103–23.

⁶ Vicat, *Recherches expérimentales...*

⁷ Vicat, *A practical and scientific treatise... translated by Captain J.T. Smith*. This translation with its extensive commentary gives a focussed picture of the rapid rise of interest in the make up and properties of various binders or cements at the beginning of the nineteenth century. A key historical reference book.

lime, but so too was aluminium provided silica was already present. Vicat also found that pozzolana was a silicate of aluminium which reacts with lime in the mortar and that tarass was a baked clay of volcanic origin with similar properties to pozzolana. He later went on to produce artificial pozzolana and to publish a book on the subject. By 1840 the French had begun to surpass the British in the quality of lime and cement and produced geological maps to identify sources of suitable materials.⁸ In Britain Col. C.W. Pasley of the Corps of Royal Engineers also undertook comprehensive research and tests on various limes, mortars, pozzolanas, and cements including those of Frost, Ranger, Francis and White. He published the results in his authoritative study of 1838.⁹

The first artificial hydraulic binder was produced and patented in 1824 by Aspdin, who called it 'Portland cement'. Davis describes the original method of manufacture and the subsequent efforts over many years to increase its strength.¹⁰ John Grant carried out extensive tests on Portland cement from 1859 before it was used in the construction of Bazalgette's London Outfall Sewer system,¹¹ which led to its widespread use in this country.

As the use of concrete in England and France grew, the manufacture of cement was changing from a craft to a science-based industry. In chapter 4 A.W. Skempton charts the history of cement, emphasizing strength and methods of testing. Tension tests were carried out on standard briquettes, and 6-inch cubes were used in compression tests, while chemical tests indicated composition. In time an understanding of the nature of cement emerged in England, France and Germany and national standard specifications appeared. Skempton suggests that there were three periods in the development of the strength of cement. The first occurred in England up to 1866, the second took place in Germany from 1875 to 1900, where chemical control and fine grinding were introduced, thus doubling the strength, while the third period (1910–50) was international, when rotary kilns and cement chemistry took strength ever further. It could also be said that the first period related to unreinforced concrete and the exploitation, by architects in particular, of load-bearing concrete walls and fireproof floors, while the second phase covers the development of early reinforced concrete, primarily by engineers, and the third, and possibly the most exciting phase, the innovative use and artistic interpretation of the essential qualities of reinforced concrete by both civil engineers and architects.¹²

⁸ Guillerme, 'From lime to cement...'.
⁹ Pasley, '*Observations on limes...*'. The best of all the early British sources for the history of cements and concrete. Also covers virtually all the foreign contemporary work, including that of Vicat, some of whose findings he disagrees with. In some cases Pasley provides the only known information on the foundations of some major London buildings.

¹⁰ Davis, *A Hundred Years...*

¹¹ Grant, *Experiments on the Strength of Cement...*

¹² Newby, 'The innovative uses of concrete...'.

The Development of Reinforced Concrete in Europe

The first use in England of mass concrete for building came in 1817 when the foundations of the newly-built Millbank Penitentiary, which were beginning to settle, had to be underpinned. In chapter 1 J.M. Crook describes the investigations into the problem and the views put forward by leading civil engineers. A proposal to use a grouted concrete foundation came from the civil engineer, John Rennie, before Sir Robert Smirke was appointed as architect for the remedial work, but he too came to the conclusion that the walls should be underpinned with concrete using a Dorking hydraulic lime. Smirke subsequently used mass concrete for the foundations of all his major works. According to Pasley, the method of construction varied between building up the concrete in layers of 6 inches to pouring it into the shuttering from a height of 6 feet.¹³

Apart from taking sole responsibility for the structure and foundations of buildings, architects were also concerned with the provision of a fireproof construction. The development of fireproof construction in England is well documented by B.L. Hurst in chapter 2. He outlines the early use of mortar and concrete in floor construction, illustrating systems where concrete slabs were supported on inverted cast-iron Tee-sections or wrought-iron I-sections. In particular he mentions early work by Foulston for suspended floors in Bodmin asylum in 1818, which eventually led to the first patented system by Fox and Barrett in 1844.

Meanwhile, William Boutland Wilkinson of Newcastle-upon-Tyne, a plasterer by trade, was taking out in 1854 the first ever patent for a system of reinforced concrete with iron bars and cables acting as tension members within the concrete. His drawings indicate that he had a clear appreciation of the structural action of reinforced concrete. Joyce Brown in chapter 3 illustrates the patent and gives results of his tests on reinforced beams. One of his small buildings, which survived until 1955, was a cottage built in the Newcastle area in about 1865, which Cassie describes as having 6½ inch deep beams, 26 inches apart, and spanning 14 to 16 feet, with moulded plaster panels forming permanent shuttering for the concrete slab.¹⁴ Unfortunately, Wilkinson was not able to market his system successfully and nothing came of the patent. Joyce Brown concludes, 'Perhaps, like most innovators, Wilkinson was a little before his time and was unable to grasp the full significance of his own discovery.'¹⁵

In France, the work of François Coignet is of particular interest and is well described by Collins.¹⁶ In 1852, Coignet attempted to build a factory with exposed

¹³ Pasley, *Observations on limes...*, 16–18.

¹⁴ Cassie, W. Fisher, 'Early reinforced concrete in Newcastle-upon-Tyne', *The Structural Engineer*, 33 (1955), 137.

¹⁵ Brown, chapter 3, 141.

¹⁶ Collins, *Concrete*, 27–35. Collins' book is a brilliant study of the history and development of concrete and its role in architecture, which has never been superseded.

concrete walls following the ancient construction system known as *pisé*, in which earth was rammed between temporary timber panels.¹⁷ After overcoming difficulties with mixes and water content on this, his first encounter with concrete, Coignet commissioned an architect to design a sophisticated four-storey house in St Denis, Paris, which imitated stonework. Because of its success he took out a British patent in 1855 entitled *Emploi de Béton*, which gave details of his method of construction and contained an addendum emphasising the complete sufficiency of concrete. 'Concrete walls need no facing materials such as stone etc. The hollow part of the mould in which the concrete is poured should have the form to be given to the mass whether the walls be plain or with projections such as cornices, string-courses...or any kind of ornament'.¹⁸ In a submission to the organising committee of the Paris Exposition of 1855, where he wished to build a concrete house, he makes a prophetic remark, 'The reign of stone in building construction seems to have come to an end. Cement, concrete and iron are destined to replace it.'¹⁹ In 1861 in his book, *Béton Aggloméré*, he wrote, 'Building cheap vaults of unusual spans for great public spaces...will not be a servile imitation of Roman works but will far surpass them in daring, elegance and economy.'²⁰ He also suggests the use of concrete with an armature of iron rods, but there is no evidence that he carried out any experiments.

Whether or not Coignet had seen, at the 1855 Exposition, Lambot's boat, which was made from a mesh of iron rods encased in a thin layer of hydraulic cement, is not recorded. Joseph-Louis Lambot had built the boat in 1848, and in 1855 he applied for a patent in Brussels covering 'iron cement as a substitute for timber' to be used both in shipbuilding and in structures having to withstand moisture, such as water tanks and tubs for orange trees. The patent also included a method of producing a beam or plank. A further boat built by Lambot was discovered in 1975 and it can be seen in Paris.²¹

The first system of reinforced concrete to progress from a simple idea to a viable system of construction was that of Joseph Monier (1823–1906), who in 1849 made flower pots using a mesh of iron rods enclosed within a mortar in a similar manner to that of Lambot. Monier took out a patent in 1867 and extended it the following year to cover reinforced concrete tanks, the first of which he built in 1872. Monier's first patent for the civil engineering use of reinforced concrete came in 1873 and covered the manufacture of arched bridges and foot bridges of all sizes; the patent included a drawing of an arched bridge with open spandrels. A patent covering beams appeared in 1877, but it lacked any real substance.

¹⁷ Collins, *ibid.*, 21.

¹⁸ Translated by Collins, *ibid.*, 28.

¹⁹ Translated by Collins, *ibid.*, 29.

²⁰ Translated by Collins, *ibid.*, 33.

²¹ *Concrete Journal* (February 1977), 24–5.

The development of Monier's patents into a workable and outstandingly successful building system only came about with the involvement of Conrad Freytag, who bought the patent rights for South Germany in 1884. The history of this development as outlined here (which differs from information given by other writers) comes from information produced by Freytag's firm and published in its fiftieth anniversary *Festschrift*.²²

Freytag's firm had been founded in 1875 in Neustadt an der Haardt under the name, Freytag & Heidschuch, as merchants for building materials, but Freytag increasingly specialized in cement and concrete construction work. On a chance visit to Trier in 1884, he saw a concrete water tank being built on the Bahnhofstrasse on Monier's instructions in order to demonstrate his system in Germany. Freytag, despite his lack of formal technical training, immediately recognized the potential of the system and barely three weeks later, in September 1884, he went to Paris with his friend, Josseaux, partner in the Offenbach building firm of Martenstein & Josseaux, to visit Monier. They saw various structures such as further water tanks and vaults and quickly agreed with him that his German patent would be acquired by Freytag & Heidschuch and by Martenstein & Josseaux. However, Josseaux was not as convinced as Freytag as to the merits of the system and only took the rights for Frankfurt am Main and the surrounding area, leaving the South German rights to Freytag & Heidschuch. The two firms also secured the first refusal for the rights in the remaining parts of Germany.²³ Immediately after the acquisition of the patent Freytag built a dog-kennel (which still exists) to satisfy himself that such a building method was indeed feasible, but the first major structures built were six bleaching tanks for a chemical works in Württemberg, which established the suitability of the material for industrial use.²⁴

The next step came with the involvement of G.A. Wayss, who had received a formal engineering education at the Technische Hochschule in Stuttgart. Wayss set up his office in Frankfurt am Main and learnt of the Monier system when Josseaux began building with it there. He approached Freytag & Heidschuch about acquiring the North German rights, which they passed over to him free of charge as they themselves were overwhelmed with work in South Germany. Wayss then acquired the remaining rights for the rest of Germany and transferred his office to Berlin, a more advantageous centre from which to develop and exploit the system. He sold on the rights for Posen and Silesia to the firm of Huber in Breslau. Thus four firms between them now owned the patent rights for the whole of Germany and seem to have worked in close co-operation with one another.²⁵

²² Wayss & Freytag, *Festschrift...1875-1925*, 5-46.

²³ Wayss & Freytag, *ibid.*, 5-6.

²⁴ Wayss & Freytag, *ibid.*, 9-10.

²⁵ Wayss & Freytag, *ibid.*, 11-12.

During the winter of 1886–87, Wayss with Freytag & Heidschuch carried out fire tests, reinforcement pull-out tests and load tests in Berlin to prove to the authorities and to the professional world that this was a reliable building method. At the same time Matthias Koenen, a Prussian State architect, produced a structural theory for the performance of Monier floors and vaults. In 1887 his work, together with the results of the tests carried out in Berlin, appeared in *Das System Monier*,²⁶ which was published by Wayss simultaneously in Berlin and Vienna. It revealed the commercial possibilities of the system, showing multi-storey buildings with a framework of cast iron encased within concrete and with arched floors. Also shown were arched bridges, the thinness of which, when compared with the equivalent stone arches, was remarkable for such a date. The age of modern reinforced concrete construction could be said to begin with the publication of this book.

In 1889 Wayss' firm became a joint stock company, changing its name to 'Aktiengesellschaft für Monierbauten', and in the same year Freytag & Heidschuch issued the first catalogue of executed Monier structures,²⁷ with an appendix giving the Monier works carried out by Wayss and by Huber. Its appearance heralded a period of expansion, which saw the acquisition of Freytag & Heidschuch by the Aktiengesellschaft and the setting up of satellite companies in Stuttgart and Neustadt, run by Freytag & Heidschuch. In 1892, after a series of technical errors caused by too rapid a growth, Wayss resigned and the company folded. Freytag then bought back the satellite firms and in 1893, together with Wayss, he formed a new firm, Wayss & Freytag, Heidschuch having died in 1891.²⁸

Let us now turn to the life and work of François Hennebique (1842–1921), whose achievements are often considered to be superior to those of Monier. He was self-taught, becoming an apprentice stonemason to a builder in Arras. At the age of 25 he set up in business on his own account. The business flourished and he gained experience in carpentry and masonry, particularly in the repair of churches, and became a public works contractor. Collins reports that in 1879 Hennebique used reinforced concrete for the first time for a building in Brussels (though unfortunately he does not give the source of the information).²⁹ Instead of timber joists, Hennebique used precast concrete beams reinforced with round iron rods to achieve a fireproof construction. From this date onwards it seems that Hennebique, in collaboration with the chief engineer for Belgian roads and bridges, began his research into the design of reinforced concrete beams, and in 1892 he patented his monolithic reinforced concrete system in Belgium and in

²⁶ Wayss, *Das System Monier*.

²⁷ Freytag & Heidschuch, *Monier und Beton-Bauwerke*.

²⁸ Wayss & Freytag, *Festschrift...*, 15.

²⁹ Collins, *Concrete*, 64.

France, presumably having satisfied himself that under fire conditions the reinforcement and concrete would stay bonded. Certainly his anchoring of the main reinforcement bars by dovetailing their ends and providing stirrups to tie the upper and lower bars in the beam shows a clear understanding of practical problems. Hennebique's firm was originally based in Brussels, but as the success of his system grew he moved to Paris. He ceased to be a contractor and proceeded to open agencies throughout Europe staffed with engineers and architects and associated contractors specially trained by him. His success was phenomenal. For instance, in 1896 alone he was responsible for over 800 building and civil engineering projects throughout Europe.

Wayss & Freytag learned of the Hennebique system during the 1890s when Martenstein & Josseaux built a large factory for the Adler Works in Frankfurt am Main using Hennebique's monolithic framed reinforced concrete construction. Wayss immediately grasped the potential of this type of construction and went to Paris in order to negotiate with Hennebique for the building rights, but was neither prepared to pay a royalty to him nor to allow his firm to become one of Hennebique's concessionaries. Instead, Wayss & Freytag exploited a loophole in the method of calculation in Hennebique's system, which enabled them to evade his patent and to build monolithic structures despite it. Their first major building was a very large eight-storey warehouse in Strasbourg constructed in 1899, a job for which they had been direct competition with Hennebique's Strasbourg agent, Züblin.³⁰

While the Monier and Hennebique systems were being developed in Germany and France, Edmond Coignet (1850–1915), the son of François, who trained as an engineer, took out various patents, first in 1890 for reinforced concrete pipes and aqueducts and then in 1892 for beams and later piles. That same year Coignet was awarded the contract to build the Paris main drainage system in reinforced concrete, thereby giving credence to this new material, as Grant had earlier done to Portland cement with the construction of the London main drainage system.

Coignet was appointed as contractor for the showpiece of the 1900 Paris Exposition, the Chateau d'Eau, a huge water sculpture over 150 feet high and 100 feet wide made of reinforced concrete, and he received a Grand Prix and a gold medal. The architect, Boileau, was entrusted with the design of a pavilion which was to represent 'Hennebique reinforced concrete' at the Exposition. Hennebique himself was consultant for the reinforced concrete floors of the Grand Palais and the Petit Palais and was also responsible for the construction of two spiral slab staircases designed by the architect, Girault, which connected the ground and first-floor levels. These were structures of great elegance and

³⁰ Wayss & Freytag, *Festschrift...*, 20–22.

beautifully expressed the spatial forms made possible by this material. Hennebique himself received a gold medal for his civil engineering structures. The Exposition, which was visited by such engineers as Robert Maillart, revealed for the first time to a wide international audience the great potential of reinforced concrete both in architecture and in construction.³¹

The success of Monier, Coignet and Hennebique inspired many others to take out patents, which usually covered only the geometry of the reinforcing bars. According to Christophe, over 100 different systems were patented and he illustrates them in his book of 1902.³² Although some of these were on show at the Exposition, only a few of them survived very far into the twentieth century.

In chapter 6 Cyrille Simonnet gives an interesting overview of the sequence of events which led to the development of reinforced concrete as a viable building material. Because it was an entirely new material, the calculation, detailing of reinforcement, specification of materials, design of formwork, mixing of concrete and the supervision of the construction works were beyond the normal experience of an architect, engineer or builder, and Simonnet suggests that these operations could only be managed by new bodies of expertise, which became known in France as *bureaux d'études*. The leading specialist contracting firms, such as Wayss & Freytag and Hennebique's agencies, each had their own *bureau d'études*. Architects could suggest structural forms, but it was the *bureaux d'études* which determined details of the final design. Simonnet also mentions the role of the various periodicals such as *Le Béton Armé* and *Beton und Eisen* in the widespread dissemination of research and practical experience. He finally emphasises the importance of the introduction in 1897 of lectures on reinforced concrete by Charles Rabut at the Ecole des Ponts et Chaussées.

Further information on Hennebique is given in chapter 7 where Gwenaél Delhumeau, who has studied the Company's archives in Paris, suggests that Hennebique set up his journal, *Le Béton Armé*, to keep his agencies and contractors as well as his clients informed of new projects, loading tests, failures, fire tests and related developments, but also to emphasize the superior expertise of his agencies over independent engineers and architects.

After its transition to a Hennebique type of monolithic structure, Wayss & Freytag also expanded enormously and from 1901 established further satellite companies in all the major German cities and as far away as St Petersburg and Buenos Aires. These were staffed by engineers who had first been trained by Emil Mörsch, who in early 1901 had been engaged as head of the technical department, at head office in Neustadt.³³

³¹ Exposition Universelle, *Revue technique...*

³² Christophe, *Le Béton Armé...*

³³ Wayss & Freytag, *Festschrift...*, 30.

In 1902 Wayss & Freytag published Mörsch's book, *Der Eisenbetonbau, seine Anwendung und Theorie*,³⁴ which gave his structural theory of reinforced concrete and made public all his experimental work for the firm. It went into many updated editions and became the standard work on the subject in the German-speaking world. By 1904, Wayss & Freytag had prepared provisional regulations for the Verband Deutscher Architekten- und Ingenieurvereine, which became the official Prussian regulations. The firm went on to acquire German patent rights for the Considère system (1904), and for Simplex piles (1907) from the Concrete Piling Co. of Philadelphia.

The Development of Reinforced Concrete in the USA

The work carried out in England, France and Germany on cement and concrete was closely observed by engineers in the USA. Jasper O. Draffin reports that cement was first required on a large scale for the construction of canals, notably the Erie Canal of 1817.³⁵ Natural cements were found in Madison County, NY, and the earliest cement works was established in 1828 near the route of the Delaware and Hudson Canal. Portland cement was first shipped from England in about 1871. Its import increased to a peak in 1896, then fell off as local production was increasingly able to supply the requirements of an expanding construction industry at a much-reduced cost per barrel. As in Europe, the USA prepared its own regulations for the production of cement and concrete.

In the early 1870s, William E. Ward (1821–1900), who had become interested in the possible use of reinforced concrete for fireproof construction, carried out tests before constructing a fireproof concrete house in 1876 in Port Chester with the architect, Robert Mock. The building, which was test loaded, is still extant and details of it are given in chapter 13 by Ellen W. Kramer and Aly A. Raafat. In 1883 Ward was persuaded to give a paper to the American Society of Mechanical Engineers on his work, which he concludes by hoping that reinforced concrete would lead to a system of fireproof construction which would merit public confidence and be universally accepted.³⁶

In 1875, while Monier was still developing his system, Thaddeus Hyatt (1816–1901) went to London from New York to promote his iron and glass block side-walk construction. While in London, he designed a building for which he devised a fireproof system consisting of upright wrought-iron plates with holes

³⁴ Mörsch, *Der Eisenbetonbau...*

³⁵ Jasper O. Draffin, 'A brief history of lime, cement, concrete, and reinforced concrete' (1943), 14–47. Reproduced in Newlon (see note 41 below).

³⁶ W.E. Ward, 'Béton in combination with iron as a building material' (1882–83). Reproduced in Newlon (see note 41 below).

through which lateral round bars were placed. The whole framework was then enclosed within a thin concrete slab. This so-called 'slab ceiling' spanned between the bottom flanges of I-section wrought-iron beams, which themselves had a separate cover of concrete. He next changed the I-section beam to an inverted Tee-section, using concrete to carry the beam compression. The inverted Tee-section was subsequently replaced by round bars, and thus reinforced concrete beams were born.

Hyatt carried out tests to confirm that iron, steel and concrete had compatible coefficients of expansion so that under fire conditions the material would not disintegrate. Tests were carried out by David Kirkaldy in London on 5ft span beams with different forms of reinforcement and the results were included in Hyatt's book of 1877.³⁷ Hyatt became over-confident in his forecast for the future of the material, offering to build reinforced concrete domes from 2ft. to 200ft. diameter which incorporated his glass lenses. Alas, he failed to obtain building permission and returned to New York. He retired from his work with reinforced concrete after patenting his system in 1878.

The first major builder in reinforced concrete in the United States was Ernest Ransome (1844–1917). He went from England to the USA in 1870 to become superintendent at the Pacific Stone Co. in San Francisco, where he stayed for four years before setting up as an independent contractor. Ransome gives a personal reminiscence in his book of 1912³⁸ and details his experience in the construction of some of the earliest reinforced concrete buildings in the USA. He patented the twisted square reinforcing bar in 1884, and in 1889 introduced the economic ribbed floor construction which is still used today. Carl Condit in chapter 14 provides many details of Ransome's buildings and gives many *Engineering Record* references to Ransome's work.

In chapter 15 John Snyder and Steve Mikesell suggest that the work of Hyatt and Ransome influenced the use of reinforced concrete in California. They refer to the earliest buildings designed by Ransome with the architect, George Percy, which introduced reinforced concrete and fireproof construction to the local building industry. They also illustrate the first reinforced concrete bridge in America, designed by Ransome in 1889, which provided the model for many other small-span bridges, which continued to be built long after Ransome had moved his office to Chicago in the mid-1890s.

Ransome remained the most prominent contractor until the late 1890s, by which time the Monier and Hennebique systems had become established. According to Draffin,³⁹ Hennebique's system was the most widely used in

³⁷ Hyatt, *An Account of some Experiments...*

³⁸ Ransome and Saurbrey, '*Reinforced Concrete Buildings*'. The first chapter, headed 'Personal reminiscence', details the life and early work of Ransome and is reproduced in Newlon (see note 41 below).

³⁹ Draffin (see note 35), 41.

America. However, the tightly-controlled single system as experienced in Europe seems to have had only a brief life in America. The structure of the 16-storey Ingalls Building of 1902, the subject of Condit's paper, was made up from a combination of the systems of Ransome, Monier, Hennebique and Considère. The Ferro-Concrete Co. of Cincinnati were the independent engineers and contractors while the architect was local.

The American Concrete Institute was set up in 1905 in order to control the growth of construction in reinforced concrete but primarily to formulate regulations. Condit comments that, 'The primary document in the history of concrete construction during the twentieth century is the *Report* of the Joint Committee of the American Concrete Institute and the American Society of Civil Engineers (1909) on the fundamental standards of reinforced concrete design. This report became the basis of all American metropolitan building codes and of much subsequent development in the theory of elasticity of reinforced concrete and the stress analysis of concrete structures.'⁴⁰

The next significant system of reinforced concrete construction was developed in America as against Europe. The Ingalls building had the standard two-way framework of beams and columns which echoed iron and steel construction, but in 1903 A.V. Turner concluded, at least theoretically, that he could do away with beams and use a flat slab supported directly on columns. He applied for a patent in 1905, building his first example in 1906. However, in 1902 Orland Norcross, an engineer from Boston, had patented and built a similar flat-slab system and Turner had to overcome the problem of infringement. Turner's patent was accepted in 1908 and he proceeded to develop his flared column capital system. Details of later tests by Arthur Lord on flat-slab construction in 1911 and the subsequent discussion on a structural design method are both included in an American Concrete Institute volume reprinting a selection of historic papers.⁴¹

The Structural Design of Reinforced Concrete

In chapter 5 De Courcy discusses the work of Wilkinson and Coignet, as the first patentees of the idea of reinforced concrete, although neither suggested any method of structural design. He also mentions the fireproof house built by William Ward, and comments on Ward's understanding of the fundamentals of reinforced concrete although he too did not provide any calculations. De Courcy is more admiring of Hyatt's work and his proposals for the structural design of beams based on an ultimate load method, though in fact these proved incorrect as he placed the neutral axis (the line or surface of zero stress) at mid-height of the

⁴⁰ Condit, *American Building Art*, 346.

⁴¹ Newlon (ed.), *A Selection of Historic American Papers...*

beam. Hatt in chapter 12 comments similarly on Hyatt's work. However, both De Courcy and Hatt agree that the first structural design method was that of Matthias Koenen, which had appeared in 1887 in Wayss's *Das System Monier*, as mentioned earlier. Koenen also put the neutral axis at the mid-height of a beam, but assumed a triangular distribution of compression stress above the neutral axis with all tension forces taken by the reinforcement. De Courcy (chapter 5) illustrates Koenen's method, which was apparently used by designers for many years, as does Hatt in chapter 12. Hatt also illustrates the method used by Hennebique, which he considers to be less correct than that of Koenen. However, the factors of safety were so high that these errors in calculations would not lead to failure. What this shows is that there was then very little understanding of how this, the first composite structural material, really acted in bending.

During the 1890s Paris had become an active centre of research and many structural design proposals were produced. Hamilton illustrates eight rival theories, including one from Edmond Coignet and Napoléon de Tédesco, on the distribution of stress across the section of a reinforced concrete beam, most taking into account that concrete could carry some tension and others assuming parabolic or non-linear compression distribution above the neutral axis.⁴²

In 1894 Coignet and Tédesco, who was co-director of Coignet's *bureau d'études*, had correctly proposed that the moduli of elasticity of both steel and concrete should be taken into account to position the neutral axis, that a triangular distribution of compression stress be assumed above the neutral axis and that no tension stresses were taken by the concrete.⁴³ This method of calculation became generally accepted as giving a good approximate solution.

The extent of the research work can be seen in Charles Marsh's book of 1904, *Reinforced Concrete*, which was the first textbook to appear in England. A much enlarged and rewritten third edition came out in 1906.⁴⁴ It includes the work of Considère with his patented system of spiral reinforcement for compression members such as columns and upper chords of trusses, and there is an extensive section dealing with calculation, which shows that the discussion of the distribution of stress through a beam was still very much alive in 1906.

Marsh also gives the Hennebique method of calculation,⁴⁵ which could well be the source of Hatt's information given in chapter 12. If Marsh is correct, it is surprising that by 1906 Hennebique had not amended his method to tie in with

⁴² Hamilton, *A Note on the History of Reinforced Concrete...* This is the first and best study of the history of reinforced concrete. Hamilton covers the period up to 1900 outside Britain, and in Britain up to 1944.

⁴³ Coignet and Tédesco, *Du calcul des ouvrages...*, 282–363.

⁴⁴ Marsh and Dunn, *Reinforced concrete*, 3rd edn. (London, 1906). A study of the technical changes between this and the first edition of 1904. It highlights the research and building works being carried out in the early 1900s.

⁴⁵ Marsh and Dunn, *ibid.*, 383–6.

the Coignet and Tédesco proposal of 1894. There seems to have been a certain amount of secrecy surrounding Hennebique's tests and method of design, though it is possible that information relating to this important aspect of his work might exist somewhere in the Hennebique archives in Paris.

In chapter 7 Delhumeau describes how the information gained from the building and demolition of the various reinforced concrete systems used at the 1900 Paris Exposition gave the Commission du Ciment Armé, chaired by Armand Considère, sufficient data to produce their official regulations of 1906, making it possible for independent engineers to design in reinforced concrete. Collins refers to the regulations of 1906 thus, 'By this act, the long efforts to create a new building material were given their final seal of recognition and from then onwards concrete was no longer a hazardous novelty, but an acknowledged medium of architectural design in the modern world.'⁴⁶ Hatt, who carried out a great deal of research on reinforced concrete from the early 1900s at Purdue University, rounds off his paper (see chapter 12), written in 1918, with an accolade on the early constructors. 'They showed a general knowledge of the strains to be resisted and a mechanical skill in meeting these strains with economical design that cannot but excite the admiration of present day constructors.'⁴⁷

However, the structures referred to in the various building regulations were of a simple nature, namely beams, slabs and columns. The original research work in France and Germany was augmented by work in the USA and, as previously mentioned, it was there that a new structural form, the flat slab, appeared, and where methods of structural design were later established. With the growing understanding of the characteristics of reinforced concrete, national standards were, and still are, being constantly updated.

Early Use of Reinforced Concrete in Australia

In order to illustrate the extraordinary rapidity with which reinforced concrete construction reached distant parts of the world, I have included D.J. Fraser's 'Early reinforced concrete in New South Wales (1895–1915)', chapter 16. The Monier system was introduced to Australia in the 1890s by a draughtsman/engineer by the name of W.J. Baltzer, who had been educated in Germany and who had made a report on the use of concrete there, taking photographs of Monier arched bridges, during a visit home. When he returned to Sydney he was able to arouse the interest of his employers, the contractors Carter Gummer & Co., who subsequently became agents for the Monier system. In order to test it they built a small experimental culvert, which was loaded to failure. They went

⁴⁶ Collins, *Concrete*, 75.

⁴⁷ Hatt, chapter 12, 34.

on to build two sewer aqueducts near Sydney in 1897, for which they had to pay a royalty of 15 per cent. However, these aqueducts were so successful, both practically and financially, that the Monier system thrived, becoming the prime method of building culverts, arched bridges and water tanks, first in New South Wales and then in other parts of Australia.

In 1906 A.V. Turner applied for a patent covering flat-slab construction with mushroom heads in Australia and carried out his first contract there in 1909, while Truscon, again from the USA, introduced the Kahn bar. The innovative use of reinforced concrete can be seen in the design of the wool store in Geelong of 1911–12 by E.G. Stone, engineer, where large latticed arched roof trusses span about 180ft.⁴⁸ The upper chords of the arches were designed on the Considère system and the roof was precast. Stone followed this in 1914–15 with a kind of Forth Bridge construction to carry the Barwon sewer aqueduct over the local estuary.⁴⁹ By 1915 reinforced concrete and the method of structural design were generally accepted and there was a ready market for a method of construction which at that time was cheaper than the traditional imported steel-frame construction.

The Early Use of Reinforced Concrete in Britain

Although Wilkinson had patented a system as early as 1854, reinforced concrete was not used again in Britain until 1897, when Hennebique's Nantes agency successfully tendered for the construction of a mill for Messrs. Weaver in Swansea, which was to have a fully-framed structure. Calculations and detailed drawings were produced in Nantes and all materials and some workmen came from there.

For this and later British contracts, Hennebique appointed L.G. Mouchel as his agent. In chapter 8 Patricia Cusack describes how Hennebique set up his British organization, training his staff and contractors as he had done in France. She notes that the majority of projects were for civil engineering or for industrial buildings, where it was not difficult to get building permission, or for railway structures, which were free of regulations. In 1909 Mouchel published a book on his organization which included a list of contracts carried out to that date.⁵⁰ He, like Hennebique, published his own journal, *Ferro-Concrete*, which first appeared in 1909. Similarly, the Yorkshire Hennebique Company in ca.1910 published details of their contracts, which included the outstanding Lion Chambers in Hope Street, Glasgow of 1908 and the 17-storey Royal Liver Building in

⁴⁸ Lewis, *Two Hundred Years of Concrete...*, 17–21.

⁴⁹ Lewis, *ibid.*, 30–31.

⁵⁰ Mouchel & Partners, *Hennebique Ferro-Concrete...*

Liverpool, begun in 1909.⁵¹ Cusack's main conclusion is similar to that of Simmonet (chapter 6) that 'the early controlled conditions of its employment in Britain, largely by Mouchel's company and Mouchel's personal dedication to the work, ensured that in a period of rudimentary knowledge about reinforced concrete, Mouchel-Hennebique design and construction was enabled to adhere to practices that worked'.⁵²

Other French engineers such as Paul Cottancin, who had been engineer for the San Marino pavilion at the 1900 Paris Exposition, later introduced their systems into Britain. Cottancin's patent involved reinforcing thin brick walls and concrete slabs with a mesh of continuously woven wire, and in 1902, when the tender price for a new Methodist church in Exeter came in too high, an English architect resident in Paris suggested that Cottancin be invited to quote. He gave a satisfactory price, but rearranged the structure to suit his system and persuaded the Exeter authorities to accept this solution. He proceeded to produce a structure with exceptionally slender members, which is described by G.J. Edgell in chapter 9. Edgell also includes a description of another extraordinary church, St Jean de Montmartre in Paris, built in 1903. Both these buildings are still extant, though some renovation has been necessary. They are examples of structural forms which can be achieved using a new material before regulations impede innovation, and Edgell writes, 'What is to be learnt from Cottancin is encapsulated in a quotation from *The Builder* in 1905, referring to St Jean de Montmartre, "The church is certainly one that deserves personal inspection and although our readers may not be anxious to emulate the example presented by St Jean de Montmartre they may learn from this building how great is the adaptability of reinforced construction and how useful is the aid offered by the system to the architect who is bold enough to break away from stereotyped methods of realising his designs."' Further information on the chequered history of the design and construction of this church is to be found in Collins.⁵³

In addition to the systems which came from France, Trussed Concrete (Truscon), which used the Kahn bar, and the Bonna or Columbian floor system came from the USA. These and many more are illustrated in detail in chapter 10 by Michael Bussell, who highlights the great variety of patented shapes of reinforcing bars. Bussell also draws attention to the appearance of hollow block floors, which became one of the standard economic methods of construction. As in France, the more bizarre systems quickly disappeared, particularly after simple round bars were shown to have a satisfactory bond with the concrete. However, all types of floors are found during refurbishment of early twentieth-century

⁵¹ Yorkshire Hennebique Co., *Views of works executed in Hennebique's patent ferro concrete by the Yorkshire Hennebique Contracting Co. Ltd. Leeds* (Leeds, ca.1910).

⁵² Cusack, chapter 8, 13.

⁵³ Collins, *Concrete*, 115–17.

construction and knowledge of their characteristics is essential for an assessment of their capability.

In another contribution to this subject, Patricia Cusack in chapter 11 considers the problem of architects having to work within the restraints of a system or to cope with the whims of the specialist engineer. She describes how the Royal Institution of British Architects set up committees to study the material and to propose recommendations for its use by architects, who were particularly enthusiastic about its fireproof qualities. Edwin Sachs, who established the British Fire Prevention Committee in 1897, was in the forefront of architects critical of the stranglehold imposed by specialist design and construction engineers. In 1906 Sachs became editor of the successful periodical *Concrete and Constructional Engineering*, which was the main source of information for the building industry in Britain. An initial lack of interest in reinforced concrete by the Institution of Civil Engineers resulted in the setting up in 1908 of the Concrete Institute as a venue for the various professionals to come together and discuss and promote reinforced concrete. Anita Witten has given further details of the Institute's composition and work,⁵⁴ noting for instance its major role in the compilation of the first regulations issued in 1915 by the London County Council, by which time reinforced concrete was finally established as a viable, economic and exciting form of construction.

Towards the Great Age of Concrete Engineering

The successful demonstration of the potential of reinforced concrete at the Paris Exposition of 1900 had a profound influence on architects, engineers, academics and on potential future clients. Two outstanding civil engineers emerge from this period, Robert Maillart (1872–1940), and Eugène Freyssinet (1879–1962). After graduating from the Eidgenössische Technische Hochschule in Zurich, and gaining experience in concrete arch building while working with various Swiss civil engineering firms, Maillart set up his own design and construction firm in 1902.⁵⁵ In 1905 he built the Tavanasa bridge, which spanned 170 feet and was the first to have all the design features of what became the typical Maillart bridge. It was a three-hinged arch made up from the curved lower slab, the upper road slab and two vertical infill walls to produce a partial box construction of minimum material and maximum elegance, quite different in appearance from the heavy arched construction of Monier and Hennebique. In 1909 he built and tested beamless floors quite independently and without knowledge of the similar work

⁵⁴ Anita Witten, 'The Concrete Institute' in *Historic Concrete. Proceedings of the Institution of Civil Engineers: Structures and Buildings* (August/November 1996), 470–80.

⁵⁵ Billington, *Robert Maillart's Bridges*, 16–29.

being carried out by Turner in the USA. However, his system of reinforcement, simpler than Turner's, showed his better understanding of the structural action of such floors. He went on to design many further innovatory structures as his appreciation of the material slowly matured.

Freyssinet studied under Rabat in Paris and at the age of 26 joined a provincial government department as a civil engineer concerned with bridge construction.⁵⁶ In 1910 he designed the Verdre bridge with a central span of 240 feet and two side spans each of 225 feet, each of three-hinged arch construction. The remarkable feature of this bridge was his use of horizontal hydraulic jacks, which were inserted at the crown of each arch and stressed in order to lift the bridge off its centring. However, after a few years, when he found that there was substantial settlement at the crowns, he simply reinserted the horizontal jacks in order to bring the bridge back to its original profile. Because of this, he realized that the concrete in the arches must have shortened under constant compression. This was the first definitive evidence of what became known as plasticity or creep, a phenomenon which had already been investigated but the importance of which had not been fully appreciated.⁵⁷

Years later, in 1955, the great engineer, P.L. Nervi, despite all his achievements and experience in reinforced concrete, admitted that there was still much to be understood about this extraordinary material. He states this with elegance and clarity in the passage from which came the opening quotation of this introduction, 'If the technique of reinforced concrete is to solve the great problems of tomorrow, we must tackle and understand the subject of concrete plasticity and of its viscous behaviour under load and in time. What is today an element of uncertainty will then become an essential factor in the successful realization of those daring structures awaiting construction in the most fruitful and generous of all building materials.'⁵⁸

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Sir Robert Smirke: a pioneer of concrete construction

J. Mordaunt Crook

Today Sir Robert Smirke (Plate V) is remembered as a Greek Revivalist, the architect of the British Museum. But his reputation as the most successful architect of the Regency period was due to his proven ability as business man and builder rather than to his popularity as a stylist. Born in 1780, knighted in 1832, he remained throughout a long life (he died in 1867) an essentially eighteenth century figure, independent of architectural competitions, basing his enormous practice both public and private on an interlocking network of Tory patronage. His most powerful patrons were the Earl of Lonsdale, Earl Bathurst and Sir Robert Peel. Thus, in 1815, he joined John Nash and (Sir) John Soane as a member of the triumvirate of government architects attached to the Office of Works: the three architect-princes of the Regency era. But besides being a fashionable stylist, an Establishment architect par excellence, Smirke was a pioneer of cast iron and concrete construction at a time when the functions of architect and engineer were not readily distinguishable. His status as an innovator rests not only on his use of concrete for foundations, cast iron for beams, girders and braces, and wrought iron for ties, joists and supports, but upon his interest in heating and ventilation,¹ his use of novel measuring techniques and his employment of quantity surveyors to ensure accurate accounting.² His importance as a constructor lay less in invention than in publicity: in his use of novel methods and materials in several widely publicised commissions. His influence on contemporary constructional technique, as in matters of style, was enormous. "Mr. Smirke," remarked one critic, "is pre-eminent in construction: in this respect he has not his superior in the United Kingdom."³

This Paper trespasses on dangerous ground: it is an historian's attempt to assess Smirke's significance as an engineer. Although it deals only with Smirke's use of concrete foundations, it could never have been written without generous help, notably that of Professor A. W. Skempton. Smirke may or may not have been the first person in this country to combine the use of concrete foundations with the use of cast iron beams. But if the data collected here has any value at all, he must surely be regarded as a key figure in the development of modern structural techniques in England. The evidence has been divided into four sections dealing with the construction of Millbank Penitentiary, the state of contemporary opinion as to the use of concrete, the development of the Savoy Precinct and Smirke's later use of concrete foundations.

¹ Smirke used several ephemeral patent processes: Perkins' system in the British Museum print room, bird room and reading rooms, in the Custom House Long Room, in his own office at 5 Stratford Place, and in his temporary Houses of Parliament. He used Price and Manby's system in the Elgin and Egyptian galleries, and Stratton and Oldham's at the General Post Office. (P.R.O. Works 4/26, f. 290; 1/23, f. 398; 1/24, f. 197; *Arch. Mag.*, 1835, II, 137; 1836, III, 91; 1837, IV, 161, 263). C. J. Richardson's *Popular Treatise on Warming and Ventilation* (1837) was dedicated to Smirke. For Perkins' system, cf. *Repertory for Patent Inventions*, March 1832; J. C. Loudon's *Gardener's Magazine*, VIII, p. 292.

² *Journal of the R.I.B.A.*, 1867, p. 205; *The Builder*, 1847, V, 23; W. Papworth (ed.), *Dictionary of Architecture* (1852-92): "Measuring."

³ *The Athenaeum*, 1828, p. 29. "He was a first class *builder architect*, . . . no building of his ever showed flaw or failing and . . . he was often called upon to remedy the defects of his brother artists." (J. Fergusson, *Observations on the British Museum, National Gallery and National Record Office*, 1849, p. 10.)

SIR ROBERT SMIRKE: A PIONEER OF CONCRETE CONSTRUCTION

I. MILLBANK PENITENTIARY

The frequency with which Smirke was invited to underprop a building in a state of "rigor mortis" won him from J. W. Croker's lips the title of "the Dr. Baillie of architects." This was his function at the County Courts, Carlisle (1810-12), Millbank Penitentiary (1817-22), and the London Custom House (1825-27). At Carlisle he inherited a building already "in a falling state . . . under circumstances which made it out of the question to ask for an estimate." Designed by Telford in 1807, and incompetently executed by the county surveyors John Chisholme and Peter Nicholson, the piling foundations proved inadequate and had to be reconstructed by Smirke.¹ At this stage it seems unlikely that he used any form of concrete. It was his "rescue" operation at Millbank which first demonstrated, on a grand scale, the value of concrete foundations.

The Millbank Penitentiary (Plate VI) for "offenders of secondary turpitude"² was opened in 1816 after a prolonged and troublesome period of gestation. The project originated in the humanitarian ideals of Jeremy Bentham, John Howard, Sir William Blackstone and Sir George Onesiphorous Paul. In 1794 Bentham contracted for the erection of a "Panopticon" Penitentiary "as far as strength is concerned, solely of cast iron and wood, in which the cast iron will greatly predominate."³ Acting as feebee for the Crown he purchased a 54-acre site from the Marquess of Salisbury for £12,000.⁴ But his inability to fulfil the contract for £36,000, plus a certain amount of official ill will, caused the scheme to languish until Romilly revived it in 1810. Bentham was awarded £23,000 to cover the cost of his expenses, and an Act of 1812 appointed three Supervisors, Lord Farnborough, George Holford and the Reverend Mr. Becher, to organise a public competition for new designs.⁵ Prizes of £200, £100 and £50 were awarded to W. Williams, C. A. Busby and J. Harvey. Revised plans by Williams were then submitted to Thomas Hardwick who agreed to supervise the works for a commission of 2 per cent. on his estimate of £239,725 plus £42,690 for foundations.⁶ Dissatisfied with this low remuneration, and pessimistic as to the suitability of the marshy site, Hardwick resigned in 1813 and was replaced by Harvey.

Hardwick's resignation was nicely timed: the foundations had already begun to sink. In 1812 Bentham had bored to a depth of 14 ft. and, on finding nothing but loose soil and peat, condemned the ground as unfit to support buildings. At first Hardwick was confident that these difficulties could be overcome by a "substruction" of wooden "planking" or sleepers. But the Supervisors thought differently. They discovered that at the "Bedlam" Hospital in St. George's Fields, James Lewis had used Yorkshire flags instead of sleepers. This prompted them to experiment with various materials tested by weights of 200-300 tons. Finally, disregarding a Blackheath architect named

¹ Cumberland County Records Office: Ac./1-6; D. and S. Lysons: *Magna Britannia*, IV, 1816, Plan; "Report from the Select Committee on the Office of Works and Public Buildings," Parliamentary Papers, 1828, IV, 391. Similarly, Smirke's foundations for Lincoln County Court (1823-30) required excavations to the "extraordinary depth" of 28 ft.; but concrete does not appear to have been used. (J. Mordaunt Crook, "The building of Lincoln County Court," *Lincs. Arch. and Archaeol. Soc. Reports and Papers*, 1962, IX, 151-7).

² J. Elmes, *Metropolitan Improvements*, 1827-9, II, p. 150; for the original rules of the prison, cf. *Gents. Mag.*, 1817, I, 511.

³ P.R.O. LRRO. 60/675; J. Bentham, *The Panopticon or Inspection House*, 1791. The radiating plan may possibly derive from Bentham's brother General Sir Samuel Bentham.

⁴ A. Griffiths, *Memorial of Millbank*, 1875, I, 24.

⁵ 52 G III cap. 44; *Monthly Mag.*, 1815, XXXIX, 302-3. Among the designs consulted were those for which William Blackburn (1750-90) had been awarded first prize in 1782 by the Commissioners originally appointed under the Penitentiaries Act, 1779 (P.R.O. Works 4/17, 20.7.1792; Works 4/18, ff. 22, 40, 41, 60; Works 6/22, ff. 50, 134; Works 1/5, f. 18).

⁶ Griffiths, *op. cit.*, pp. 31, 34-5, citing Supervisors' Minute Book, 1812. J. I. Hawkins, one of the 43 competitors, claimed that Spencer Perceval secretly agreed to appoint an architect who would use the winning designs. (*Arch. Mag.*, 1835, II, 374-5.) Certainly, apart from the entrance, Hardwick closely followed Williams' designs which in turn followed Bentham's. (*The Builder*, 1868, XXVI, 181; R. Ackermann, *Repository of Arts*, 1812, VIII, 157; 1817, III, 153.) Williams, of 11 Tichborne Street, Golden Square, had taught drawing at Sandhurst.

SIR ROBERT SMIRKE: A PIONEER OF CONCRETE CONSTRUCTION

Alexander, who claimed knowledge of a secret and unique system of foundations,¹ they instructed Hardwick to seek advice from John Rennie, S. P. Cockerell, James Lewis and Robert Browne. This quartet recommended that the topsoil and alluvial substrata consisting of "vegetable earth, light clay and morelog" should be excavated and that upon the gravel bed should be laid "puddled walling" composed of "gravel or ballast only, having perpendicular sides, cast and mixed in lime-water, with a small quantity of sand".²

This report was dated 22nd January 1813, and Rennie's seems to have been the dominating voice. The terminology is confusing, but the ingredients of concrete seem to be there. Puddling was of course the crude method of packing suitable earth to make canals and ponds watertight.³ However, Hardwick's lack of interest, Harvey's incompetence and the Prison Supervisors' desire for economy made sure that this report was never fully implemented. It was a report, not a specification, and its recommendations were only made with regard to the main body of the building: the central chapel, the surrounding hexagon and the six radiating pentagonal salients, each three storeys high with angle turrets and a central "Taskmaster's Tower."⁴ (Plate VI (b)). Hardwick's brief tenure of office was almost entirely concerned with the construction of the outer walls and entrances. The Pentagon foundations were only begun in the summer of 1813, and Hardwick resigned in the autumn. The octagonal boundary wall was given a foundation of rammed rubble no more than two feet thick; and the outer lodge and gateway, with its massively rusticated archway designed by Hardwick, was founded partly on rubble and partly on piles.⁵ A few weeks before Hardwick's resignation the foundations of both wall and gateway began to subside.

For the next three years the Penitentiary was the responsibility of John Harvey. No reputable architect would accept a stipend of only 2 per cent. His gross inefficiency had already lost him one official appointment, at the Office of Woods and Forests.⁶ At Millbank he again proved gouty and incompetent. The Supervisors had been lulled into believing that with regard to foundations Harvey possessed "more experience . . . than many architects of greater general knowledge."⁷ Harvey first proposed an additional foundation of strong flat stones and then finding stone difficult to procure, used three courses of brickwork laid in Parker's cement.⁸ By May 1816 little more than one third of the building had been executed, £128,304 had been spent and £228,813 was still required.⁹ Less than three months after their arrival in June, the first prisoners (36 women from Newgate) in Pentagons I and II were "under considerable fear and alarm," as cracks and fissures began to divide the walls. At this point Harvey was dismissed and Smirke was called in at the usual rate of 5 per cent. commission.¹⁰

¹ "Independent of piles, planking and brick piers as arches . . . not subject to alteration by floods, damp, heat, frost, or any failures by time . . . neither pervious to vermin, nor liable to be undermined by prisoners." (Griffiths, *op. cit.*, p. 36.)

² *Ibid.*, p. 37; *Proc. Inst. C.E.* (1856-57), XVI, 434.

³ "Puddle is formed by taking a quantity of earth, and mixing it with water, gradually poured upon it, to the consistency of mortar . . . It is applied . . . in horizontal layers or courses of about 9 in. in depth, and is mixed by men treading on it with mud boots, and stirring it with shovels. Each layer . . . is left to dry, until a man may stand on it without sinking . . . Clay and garden mould, or vegetable earth, are not good for forming puddle; the best kind of earth for that purpose being a lightish loam, mixed with coarse sand or fine gravel, all particulars of which, exceeding the size of a musquet ball, should be rejected. Puddle, when suffered to become thoroughly dry, cracks . . . but when properly made and either brought into immediate use or kept moist until required, it is impervious to water." (C. W. Pasley, *A Course of Military Instruction* (1817), III, 692-3.)

⁴ Plans given by G. Holford, *Account of the Penitentiary at Millbank* (1828).

⁵ Engraving in *Monthly Magazine*, 1814, XXXVII, 5.

⁶ P.R.O. Crest 8/3 passim.

⁷ Holford, *op. cit.*, p. xxix.

⁸ Griffiths, *op. cit.*, p. 39.

⁹ *Ibid.*, p. 40; *Commons Journals*, 1816-17, LXXI, 394, 649.

¹⁰ Griffiths, *op. cit.*, p. 42, citing the *Governor's Journal*, 21.9.1816: "all three angle towers [in Pentagon I] . . . sunk a little lower, which cracked the arches and wall in several places . . . Sent for Mr. Harvey . . . Talked to prisoners and assured them there was no danger and succeeded in pacifying them" (Holford, *op. cit.*, pp. xxxi-ii).