7.05 Reinforced Concrete

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a. proto-reinforced concrete in Australasia

The idea of reinforcing mass concrete with metal was a fairly natural one, but it has little to do with the modern concept of reinforcement designed on scientific engineering principles, and a lot to do with the sort of casual timber and other reinforcement sometimes used in earth constructions.

In New Zealand, where mass concrete was more widely used, these informal essays in reinforcement seem - from G C Thornton's account [1] - to have been more common than in Australia. In 1878 Thomas H White designed two storey flour mill store at Ngaruawahia on the Waikato river bank, reinforced with single strand barbed wire. White claimed that this was the first concrete building in the southern hemisphere to have reinforcement.[2] Another pioneering use of a sort of reinforced concrete was the water tower at Addington Railway Workshops, Christchurch, designed by Peter Ellis, Chief Draughtsman for the Railways Department and built in 1882. It is an octagonal tower of solid wall construction, reinforced with several tonnes of scrap steel, but what the sections are is not recorded.[3]

The use of concrete and iron in 1894 for the complete structure of the police lock-up at Broome, Western Australia, has been mentioned already. In concrete engineering works, as well as in some conventional buildings, railway line was often used - especially in those by the Tasmanian architect Alexander North, such as the vaults of St John's, Launceston, of 1910-11.[4] North was using reinforced concrete in a number of buildings around Launceston at this time, and they were probably all reinforced with recycled iron of some sort. His own house at Holm Lea, Rosella, of about 1910, was reinforced with miscellaneous iron such as bed springs. His interest in reinforced

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1 G G Thornton, 'Early Concrete Structures in New Zealand', *Fourth National Conference on Engineering Heritage 1988, Sydney 5-8 December 1988, Preprint of Papers* (Barton [ACT] 1988), p 87.

2 P R Wilson, 'The Architecture of Samuel Charles Farr 1827-1918' (MA, University of Canterbury, 1982), p 62; Thornton, 'Early Concrete Structures', p 87.

3 Thornton, 'Early Concrete Structures', p 87; Geoffrey Thornton, *Cast in Concrete* (Auckland 1996), pp 66-7.

4 Verbal information from John Maidment, Melbourne.

concrete was possibly fostered by his brother-in-law, the engineer Reed Bell, and his sometime partner Harold Masters.[5] At Mangana, in the Fingal Valley, North designed the Roman Catholic church of Our Lady of the Sacred Heart in 1910 entirely of reinforced concrete. However nothing is known of the nature of the reinforcement used here, nor in an Anglican church in northern Tasmania which he designed about the same time.[6]

During the 1890s there were local experiments with two more advanced systems which could technically be described as reinforced concrete, but which did not adhere to the principle of using the iron only in tension and the concrete in compression. Both appeared in Queensland. One was the use of expanded metal, further discussed below, and the other the Wunsch system of bridge construction. Alfred Brady's Lamington Bridge, opened on 30 October 1896, was in fact the only Australian work to receive any international attention or recognition, for it was published by Paul Christophe in his *Béton Armé et ses Applications* of 1892,[7] and a paper by W N Twelvetrees in *Concrete and Constructional Engineering.* [8] It was designed on the system developed in 1884 by the Hungarian Robert Wunsch, and Brady thought of it as a series of arches, though it is arguably more like a continuous slab-type girder. It involved a series of wrought iron or steel frames - in this case Vignoles pattern railway line - set within the mass of cornet - pieces horizontally below the deck and others curved around the soffit of the arch. It was not to be the largest span of the type (for the Emperor Bridge at Sarajevo, of 1897, was a single span of 25.4 metres), but it was possibly the most substantial Wunsch bridge in the world, and certainly the largest outside Europe. It consisted of eleven spans of each of 15.2 metres clear, or 16.6 metres between pier centres[9]

It cannot be said that Australia itself has made any significant contribution to the evolution of true reinforced concrete, but nor can it be said that this was for want of trying. We have seen already that George Taylor proposed his own system of reinforcement, and we will see below that there were local innovations in concrete house building which were in varying degrees useful and/or original. Another innovative system is that of a grain silo at 'Horsley', New South Wales, of 1909, which has approximately 50 x 50 mm tees vertically at 600 mm spacing, bound around horizontally with flat bars of about 50 x 12 mm, and over these [vertical?] wires of about 6 mm diameter. The concrete has been applied as a render to either side of this framework to a thickness of about 130 mm.

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5 North's other works in concrete included concrete silos at Ritchie's Mill, Cataract Gorge, Launceston, of 1912; Our Lady of the Sacred Heart, Mangana, of 1910; and the San Miguel warehouse in Elizabeth Street, Melbourne, built on the KM system in about 1915. Information from John Maidment, 1997: see also J Maidment, 'Alexander North (1858-1945)', in G Bolton et al [eds], *Australian Dictionary of Biography,* XI (Melbourne 1988), pp 38-9. The date for Mangana is from Brian Andrews, *infra*

6 Information from Brian Andrews, 30 June 1999.

7 Paul Christophe, *Le Béton Armé et ses Applications* (Paris 1902), pp 258-263.

8 W N Twelvetrees, "Reinforced Concrete Bridges II', *Concrete and Constructional Engineering,* I 4 (September 1906), pp 261-3.

9 A B Brady, 'Low Level Concrete Bridge over the Mary River, Maryborough, Queensland', in Institution of Civil Engineers, *Minutes of Proceedings,* CXLI (1899-1900), pp 246-257 & pl 4.

True reinforced concrete took off especially in Auckland and the North Island of New Zealand. There were two factors which encouraged this: the availability of Portland cement from two factories in the area, and the severity of depredation by the teredo in wooden marine works. The Australasian Ferro-Cement Company did a great deal of work, notably the dramatic span of the Grafton Bridge, Auckland, opened in 1910. By contrast, houses were generally of mass or block construction rather than being reinforced, notwithstanding occasional claims to the contrary.

b. raft construction

The principle of placing a building on a great mass of concrete, which goes back to the Millbank Penitentiary, is not far removed from that of a structural raft. It was common to add a certain amount of iron, more to tie the mass together than to perform any specific structural role. However in 1882 J W Root devised a 'floating raft' to carry the Montauk Block on the soft foundations offered by the Chicago subsoil. Layers of iron rails were set within a 500 mm thick mass of concrete, and both the architect and his client saw this not as a concrete foundation, but as a steel one, which was embedded in concrete to protect it from rusting.[10] In the Tacoma Building, of 1886-9, I-beams were used in a concrete raft which was again 500 mm thick,[11] and in 1890 W L B Jenney used a concrete and rail raft for the Home Insurance Building.[12] Rather similarly in Australia 'the heaviest steel rails' were used in the mass concrete foundations of the house 'Oma' in Toorak, of 1889 'so as to prevent settlement',[13] and in 1891 a specification for a cottage in Melbourne required the builder 'to lay in the concrete under all walls ... a double row of old railroad iron of a weight not less than 68 lbs per yard'.[14] These were of course strip footings rather than rafts.

By the time of the Great War a number of raft slabs had been built in Australia, one of the most interesting of which was that of the South Melbourne Gasworks, designed by P C H Hunt, using expanded metal reinforcement, in which context it will be discussed below. Of the earliest of the more conventional raft slabs was that of the Sailors Rest, Geelong, of 1912.[15] By the mid-twentieth century raft slabs were widely used overseas, though there was considerable variations in detailed practice,[16] and it was after World War II, that the flat slab on the ground became a standard element for domestic use in Australia. It has been claimed that Harry Seidler's Williamson House in Mosman, Sydney, was in 1951 'the first Australian house to be built of slabs of

10 C W Condit, *The Rise of the Skyscraper* (Chicago 1951), p 77.

11 Condit, *Rise of the Skyscraper,* p 170.

12 Theodore Turak, *William le Baron Jenney: a Pioneer of Modern Architecture* (Ann Arbor [Michigan] 1986), p 292.

13 *Argus,* 21 April 1890, p 3.

14 Flannagan & Foy, 'Specification of the Materials ... of a double brick caretaker's cottage in Clifton Hill for the Dramatic and Musical Association of Victoria', 1891, Melbourne University Architectural Collection, State Library of Victoria, quoted in notes by Hanut Singh-Dodd, 1995.

15 *Building,* IV, 12 February 1912, p 64.

16 C P Sorensen, *Solid Concrete Slab Floors* [Commonwealth Experimental Building Station: technical study no 38] (Sydney 1955), pp v, 31.

reinforced concrete without the need for heavy foundations',[17] but this appears to be a confusion arising from the flat plate construction of this house, discussed below, for the house is at least partly carried on large piers.

The change in local practice was actually wrought by the CSIRO Division of Building Research, whose work in association with Swinburne College established that raft footings designed only by rule of thumb were more than adequate over most soil conditions.[18] This resulted in a Commonwealth Experimental Building Station report in 1955,[19] in an amendment to the Victorian *Uniform Building Regulations,* and ultimately in the adoption of Australian Standard AS 2870-1986.[20] The change was not unopposed. In 1955 the War Service Homes Division refused to make the final payment on a house in Bankstown, New South Wales, because it was built with a reinforced concrete slab on the ground, The builders, Golf Club Investments, offered to dig under the slab or to x-ray it to prove its soundness.[21]

c. the Monier system

It was in 1894 that true reinforced concrete made its appearance in Australia, though for the first decade was confined to major engineering works, which need not concern us here. It is important, however, to know that it was the Monier system that was used, and that this was introduced by Carter Gummow & Co (later Gummow, Forrest & Company) in Sydney. The striking aspect of the Australian scene is that the Hennebique system, so prominent in Europe, had little impact, and even that only - it seems - at a later period. This is probably because it was associated with Hennebique's own contracting business, for which the small Australian market probably held little attraction, and it was unlikely to be taken up by other parties.[22]

Carter Gummow appear to have built a single Monier arched culvert under the Parramatta Road, Burwood, which may yet survive,[23] and they obtained the contract for the Forest Lodge Sewage Aqueduct, Sydney, two arches for which were tested on 11 and 20 September 1895.[24] This comprises two separate structures, the Johnstone's Creek and the White's Creek aqueducts, and leads ultimately to the Bondi Ocean Outfall Sewer. In date it is only two years after the world's first reinforced concrete

17 Susan Wyndham, 'Historic Seidler House to be Razed', *Sydney Morning Herald,* 5 February 2001.

18 Brian Ferguson, 'Changes in Concrete', in Miles Lewis [ed], *Two Hundred Years of Concrete in Australia* (Sydney 1988), p 123.

19 Sorensen, *Solid Concrete Slab Floors,* passim.

20 Ferguson, 'Changes in Concrete', p 125.

21 *Cross-Section,* no 33 (1 July 1955), p 2.

22 For Hennebique, see Gwenaël Delhumeau, 'Hennebique and Building in Reinforced Concrete around 1900', in Frank Newby [ed], *Early Reinforced Concrete* (Ashby), pp 135-153, and Patricia Cusack, 'Agents of Change: Hennebique, Mouchel and Ferro-Concrete in Britain, 1897-1908', *Construction History,* III (1987), pp 61-74.

23 B S El-Hazouri, 'The Development of Reinforced Concrete in New South Wales, 1918-1940' (MEngSc, UNSW 1985), p 16.

24 *A Treatise on Improvements in Concrete & Cement, Mortar-Building, Construction & Manufacture, Combined with Iron Rods* ([typescript published by Carter, Gummow & Co] Sydney 1896), no page.

aqueduct, that built over by Edmond Coignet,[25] and it consists of numerous twenty-five metre arches. It is still in use, though various preservation measures have had to be taken, including increasing the depth of reinforcement cover in the arch soffits from about 12 mm to 30 mm, done in 2002.[26] An interesting transitional example is the Centennial Park Reservoir in Sydney of about 1896-7, for which the Water Board engineers prepared at least three sets of drawings, one of which used Monier reinforcement,[27] though the structure was not in fact built on the Monier system.

On 1 January 1896 Carter, Gummow & Co produced an account of the Monier system by W G Baltzer, who had been in Europe studying it. This typescript entitled *A Treatise on Improvements in Concrete & Cement, Mortar-Building, Construction & Manufacture, Combined with Iron Rods*[28] is the first local text of any sort on the subject of reinforced concrete. It has various pictures pasted in, and a number of wash tinted drawings, and presumably was meant for internal use, or for agents of the company, like Monash & Anderson in Melbourne. In 1898 the company established works for making Monier pipes and other precast items.[29] Carter, Gummow & Co later became Gummow, Forest & Co, and was then acquired by the New South Wales government to become the State Monier and Concrete Pipe Works.[30] Their executed work was more in the field of engineering than that of architecture, and sometimes shows the direct influence of the published European texts, as in the case of the Bradley's head Lighthouse, Sydney Harbour, of 1904.[31]

F M Gummow was a graduate of Melbourne University's engineering school, and in 1897 approached Professor W C Kernot, of the university, and obtained his support for the new system. He then approached William Davidson, Inspector-General of Public Works, and was allowed to tender for a Monier bridge over the Yarra in place of a steel girder structure which had been proposed on the line of Anderson Street, South Yarra.[32] Carter Gummow & Co's price was much cheaper, and they obtained the contract and immediately entered into a temporary agreement with the engineers Monash & Anderson to become Victorian agents for the Monier system. Bridges at Fyansford and Creswick followed in about 1899-1900,[33] though for legal and other

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25 The aqueduct at Achères, Seine-et-Oise, bu Edmond Coignet in 1893 is credited as the first built of reinforced concrete in *Cent Ans de Béton Armé* (Paris 1949), p 36. Another aqueduct over the Vanne, built as part of the Paris water supply system, by 'the late François Coignet' is illustrated in Frederick Rings, *Reinforced Concrete: Theory and Practice* (London 1910), fig 1, pp 2-3.

26 Information from John Lambert of Sydney Water, 2002..

27 Copies of drawings held by Carl and Margaret Doring: Centennial Park Reservoir, part section and plan, 19 October 1896; full plan, 5 January 1897; Monier arches, 5 January 1897; undated detail (possibly as built). .

28 *A Treatise on Improvements in Concrete & Cement, &c*, as above. This may be based upon G A Wayss, *Das System Monier (Eisengerippe mit Cementhumhüllung) in seiner Auwendung auf das gesammte Bauwesen* [The Monier System (iron skeleton with cement covering) in its application to building] (Berlin 1887).

29 *Building*, 12 May 1911, p 28.

30 *Building* (Auckland 1996), pp 66-7.

31 See Wayss, *Das System Monier* , p 117. The lighthouse is illustrated in *Building*, 18 February 1908, pp 65-6.

32 G W Mitchell, *Genesis and Development of Reinforced Concrete in Australia* (Sydney 1922), pp 5-6.

33 Serle, *John Monash*, pp 131, 134-5.

reasons Fyansford was a financial disaster. J T N Anderson was the partnership's Monier specialist at this stage, and began to design in the Monier system, but John Monash was soon to catch up, particularly as he could read the technical literature in the original German.[34]

In 1903 William Baltzer visited John Monash, bringing copies of the Wayss handbook - presumably the 1902 handbook by Emil Mörsch[35] rather than the 1887 one which Baltzer had previously translated - and of Paul Christophe's *Le Béton Armé*.[36] In May of 1902 the shire engineer of Mansfield had approached Monash & Anderson to quote on a bridge over Ford's Creek, and Monash had submitted costs for an arch span. But there was a delay on the shire's part, and by the time the project was revived in 1903 Monash believed that T-girders were preferable to arches, having familiarised himself with German literature on the subject.[37] The council preferred the arch, and this was the form built in 1903,[38] but Monash was able to adopt the girder form in later structures such as the Hindmarsh Railway Bridge, Victor Harbour, South Australia, of 1907.[39] When the partners split up it was John Monash who in 1905 acquired the rights for Victoria and South Australia, and set up his own operation, the Reinforced Concrete & Monier Pipe Construction Company, with the financial backing of the cement manufacturer David Mitchell.[40]

Whereas Carter Gummow's work was at first confined to engineering structures, Monash was quickly involved in the use of reinforced concrete for city buildings in Melbourne. The first inner city building was Bank Place Chambers, commissioned in 1904, but it took a considerable battle with the Building Surveyor's Department before it was built in 1905-6.[41] It was also in 1905-6, in the inner suburb of Kensington, that he built two reinforced concrete stores for the Australian Mortgage Land and Finance Company, one of one and one of two storeys.[42] These had monolithic concrete frames and were not otherwise particularly remarkable, though it appears from the drawings for the same company's wool store a little later that Monash at first contemplated a clear span of 29 metres over the top floor.[43]

Bank Place Chambers still had brick outer walls, and much more remarkable was the pair of buildings in Oliver Lane of about 1905-7, which were to house Monash's own

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34 Serle, *John Monash,* p 153.

35 Emil Mörsch, *Reinforced Concrete Construction: Theory and Practice* [later translation of *Der Eisenbetonbau*] (no date or place [c 1902]).

36 Information from Alan Holgate, 2002. A copy of volume 2, of Christophe, reproducing drawings of European examples in folio format, is in the John Monash collection at the Australian National Library.

37 Alan Holgate et al, 'History of Ford's Creek Monier arch bridge, Mansfield, Victoria', http:/home.vicnet.net.au/~aholgate/jm/texts/fordshist.html, consulted 7 April 2004.

38 Illustrated, *Building,* 14 December 1907, p 37.

39 Illustrated, *Building,* 18 January 1908, p 54.

40 Serle, *John Monash,* pp 154-5.

41 Serle, *John Monash,* p 154; *Building,* I, 4 (14 December 1907), p 42; Royal Victorian Institute of Architects, *Journal*, January 1906, pp 199-202.

42 John Monash, 'Notes on a Contemporary Example of a Reinforced Concrete Structure', *Proceedings of the Victorian Institute of Engineers,* VII, 6 June 1906, pp 42-3; Geoffrey Serle, *John Monash: a Biography* (Melbourne 1982), p 154.

43 Monier Co file no 605, Melbourne University Archives.

offices and those of his supporter Mitchell.[44] Here there is no brick cladding, but a complete concrete structure resembling those which Frederick Ransome was building in the United States.[45] It was possible to build in this way only by obtaining a dispensation from the requirements for wall thicknesses under Melbourne building regulations. In 1907 these regulations were modified to allow both steel and concrete framed buildings to have thin non-structural walls, referred to as 'curtain walls', though not necessarily conforming to today's definition of the term.[46] The Oliver Lane buildings seem to have been the first conventional buildings in Australia constructed wholly of reinforced concrete. In 1913, when conventional reinforced concrete framing had yet to appear in central Sydney, the Melbourne *Argus* described as a novelty a new building on the corner of Queen and Little Collins streets.[47] John Monash made a point of correcting this, and named a number of central Melbourne buildings of the same construction.[48]

When the great octagonal reading room of the Melbourne Public Library was proposed - at 34.8 metres the largest reinforced concrete dome in the world (albeit only briefly so) - it was seemingly taken for granted that it would be in Monier concrete, and a design was obtained from Monash. However G A Taylor, the editor of *Building,* had already been campaigning against the Monier monopoly, and he was now joined by the Master Builders Association, which forced the trustees to open the contract to competition. The winning tender in 1909 was that of the builders Swanson Brothers, using reinforced concrete of the Trussed Concrete Steel Co of England. The external dimensions of the dome members appear to have been little changed.[49] The floor of this room is a slab carried on a network of radial and tangential beams, again of dimensions similar to those proposed by Monash, but carried onto the columns below by polygonal cone heads. The use of conical column heads beneath a slab carried on beams was characteristic neither of the Kahn nor the Monier system,[50] and is an odd hybrid probably attributable to the influence of the conical heads in the nearby Sniders & Abrahams building.

Monash was in turn to introduce reinforced concrete to South Australia, where in 1904 the local architect Frederick Dancker had been the first to call for the use of reinforced concrete walling.[51] Monash established the South Australian Reinforced Concrete Co. Ltd. in 1906.[52] In 1907-8 he was building not only engineering

44 *Building,* I, 2 (15 October 1907, p 58; I, 4 (14 December 1907), p 59.

45 Particularly the second stage of the Pacific Coast Borax Company factory, Bayonne, NJ, of 1903. See Reyner Banham, 'Ransome at Bayonne', *Journal of the Society of Architectural Historians*, XLII, 4 (December 1987), pp 383-7; ibid, *A Concrete Atlantis* (Cambridge, Mass, 1986), pp 72-80.

46 *Building,* I,2 (15 October 1907), p 58.

47 *Argus,* 21 January 1913, p 5.

48 *Argus,* 22 January 1913, p 11. These were the Oliver Lane buildings; the Gippsland Co-operative Butter Company; Queensland Insurance Company; McCracken's Building; the central block of Collins House; a warehouse in Elizabeth Street; and Condell's Building.

49 Miles Lewis, *Two Hundred Years of Concrete in Australia* (Sydney 1988), pp 12-14.

50 Christophe, *Le Béton Armé,* p 118.

51 Presumably in his *Modern Dwellings: 100 Selected Designs,* 1904: Jim Faull & Gordon Young, *People Places & Buildings* (Adelaide 1986), p 103.

52 Geoffrey Serle, *John Monash,* p 164.

structures, but some commercial buildings,[53] of these, Kither's Building in King William Street, was the first major example in Adelaide.[54] This survives today in a defaced condition. In 1909 H G Jenkinson became the Adelaide manager of the South Australian Reinforced Concrete Co, but in 1923 he set up as a private consulting engineer in partnership with M S Stanley.[55] In 1908 the Reinforced Concrete and Monier Pipe Company was a subcontractor in the construction of the Commercial Bank in Launceston, where the floor slabs at least are of reinforced concrete, though the nature of the columns is unclear.[56] In 1911 Robert Law established the Monier Patent Proprietary Company Ltd in Western Australia, but with the object only of manufacturing pipes.[57]

By 1919, now freed of the earlier restrictions which had as applied in Sydney, the twelve storey Union Steamship Company building was erected to the design of Manson & Pickering, and was described a 'the first and largest ... reinforced concrete building in Sydney.'[58] Next the Astor Building, a cooperatively owned block of flats built in Macquarie Street in 1923, became, at thirteen storeys, the highest reinforced concrete building in Australia.[59] The cause of reinforced concrete received a severe setback with the collapse in 1925 of the British Australasian Tobacco building, Melbourne. It was a six storey reinforced concrete frame building facing Swanston Street, designed by the architect F J Davies. On 24 April the fifth floor at the back of the building, fronting Stewart Street, collapsed without warning, and in turn penetrated the fourth floor below.[60] Subsequent investigation showed that the concrete was very sandy and had been mixed with excessive amounts of water, so that the underside of one beam showed layers of laitance up to 100 mm thick.[61]

d. expanded metal

The first potential challenge to the Monier system came in the use of expanded metal, which was already in use as a lathing for plaster, as discussed below. It was not used to reinforce concrete until about 1890,[62] and it was effectively introduced to Australia for this purpose under the aegis of the Queensland Government Architect A B Brady, who had already pioneered the local use of the Wunsch system of bridge construction in his Lamington Bridge at Maryborough.[63] The term 'effectively' is appropriate

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53 Geoffrey Serle, *John Monash*, p 164.

54 *Building*, 15 October 1907, p 11; 18 January 1908, p 74: the latter report claims it as the first building in Australia wholly of reinforced concrete, but this is clearly incorrect.

55 D A Cumming & G C Moxham, *They Built South Australia: Engineers, Technicians, Manufacturers, Contractors and their Work* (Adelaide 1986), p 111.

56 Though the building survives, no drawings have been located. The building was later the ES&A, and then the ANZ Bank. Alan Holgate by email, 4 April 2004 (acknowledging the assistance of Lionel Morrel of the National Trust).

57 Bryce Moore, *From the Ground Up* (Nedlands [Western Australia] 1987), p 47.

58 *Building*, XXIV, 141 (12 September 1919), pp 54, 112.

59 *Sydney Morning Herald*, 26 October 1923, p 8.

60 *Argus*, 25 April 1925, pp 33-4; 27 April 1925, p 13; 28 April 1925, p 11.

61 M T Shaw, *Builders of Melbourne* (Melbourne 1972), pp 52-3, 74.

62 B E Jones [ed], *Cassell's Reinforced Concrete* (London 1913), p 8.

63 Evelyn Drury et al [eds], *Architects', Builders' and Civil Engineers' Reference Book* (London 1950), p 416.

because at least one structure had been built before this date. In 1896 there was put up to auction a house at Cowes, Victoria, described as being of expanded metal, cemented outside and plastered within.[64] The Annual Report of the Queensland Department of Public Works for 1902-3 described progress on the new Lands and Survey Offices (now known as the Lands Administration Building), and stated that 'the employment of expanded metal lathing, as a re-enforcement [*sic*] to the strength of the concrete floors and ceilings in the building, is a new form of construction in this State, and is expected to show highly satisfactory results'.[65] It was in fact, so far as we know, new not only to Queensland but to Australia as a whole.

The way in which expanded metal was used did not approach the character of reinforced concrete in the Monier sense. The flooring systems were supported on rolled wrought iron or steel beams, which were encased in concrete. In what seems to have been the original system devised by Golding, shallow segmental arches spanned between these beams and carried in turn a flat slab reinforced with the expanded steel.[66] There were other systems involving suspension straps in catenary form, all cast into concrete; continuous segmental vaults with the expanded metal curved around the surface; and simple beam and slab combinations. The earliest structural use of the material to be reported in the handbook was in the reservoir of the Rockford Waterworks, Illinois, of 1893.[67] Rather surprisingly the handbook issued by the American producers in 1896 stated that 'there are large factories in Europe and Australia with a constantly widening use of the system'[68] and, as we will see, the material had indeed been manufactured in Melbourne, on at least a small scale, from 1889.

So far as Britain was concerned, and by extension the Australian colonies, the critical year was 1897. Practical experiments were undertaken by Sir John Fowler and Sir Benjamin Baker at an unspecified date, probably about 1896, and in 1897 the Expanded Metal Company of London its handbook, *Some Particulars concerning 'Expanded Metal'*. This was in many respects derived from the American publication, and reproduced some of the same illustrations, but it also reported the results of the Fowler and Baker tests. It contained an extensive list of British buildings in which expanded metal had been used, but it was not explicit about how: the probability is that most or all were examples of its use as lath for plastering, not for the reinforcement of concrete.[69] The Expanded Metal Co was still selling the material in 1950, under the name 'Expamet', together with associated products.

The construction details of the Lands Administration building have not yet been established, but major parts of the concrete flooring are carried on segmental arches, and are known, from the working drawings, to be carried on steel beams. This is exactly consistent with the Expanded Metal Co's system I of fireproof floor

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64 *Argus,* 7 November 1896, p 2.

65 Queensland, Department of Public Works, *Annual Report for the Year 1902-1903,* p 2.

66 Expanded Metal Co, *Expanded Metal in Fire-Proof Construction* (Chicago 1896), p 9.

67 *Expanded Metal in Fire-Proof Construction,* p 32.

68 *Expanded Metal in Fire-Proof Construction,* p 4.

69 Expanded Metal Co, Limited, *Some Particulars concerning 'Expanded Metal', its production and uses in Fire-Proof and other Building Constructions, &c* (London 1897).

construction, which was the form originally used by Golding.[70] It seems likely that it conforms to this system in all material respects, including the use of segmentally arched steel channels. Like many other aspects of this building it can be seen as part of a continuum with the Brisbane Treasury, where a more primitive fireproof flooring system had been used. It is the only known example of the original Golding system in Australia, and is also the oldest identified use in the country of expanded metal in any form, though there must have been many earlier.

Within a year or two of the completion of the Lands Administration Building, expanded metal was being marketed fairly extensively in Australia, often in association with the Kahn bar. In 1906 J W Pender used the material in association with flat wrought iron bars in the footings of 'Belltrees' homestead at Scone, New South Wales.[71] By 1908 Elliott Maclean & Co of Sydney were agents for expanded metal, at least in New South Wales,[72] but subsequently it was sold in Australia by the Expanded Steel and Concrete Products Co, which also dealt in concrete mixers and 'Pudlo' cement waterproofing compound.[73] Expanded steel was used most effectively as reinforcement for slabs, for example in a double layer raft slab at the South Melbourne gasworks in 1907, designed by P C Holmes Hunt.[74] At about the same time the engineer C A D'Ebro produced a remarkable structure at Borthwick's meat works, near Melbourne, in which the whole of the reinforcing of walls and floors was of this material.[75] In 1908-9 it was used in conjunction with Kahn bars for a structure bridging the Reilly Street drain in Collingwood, which shortly afterwards collapsed.[76]

In Sydney expanded metal was used in 1907 for the floor slabs of Challis House in Martin Place, a steel-framed building designed by Robertson & Marks in conjunction with the Government Architect, W L Vernon.[77] Soon afterwards the material was used in the head office of the Commonwealth Bank; the Sunday Times newspaper office; the American Tobacco Factory in Castlereagh Street, by C H Slatyer; the Andrews Brothers warehouse in King Street; Dr McCormack's residential chambers in Macquarie Street; the Bennett & Woods warehouse in Pitt Street;[78] chambers in Castlereagh Street designed by G M Pitt for Phillip Charley;[79] a motor garage in Castlereagh Street, by E A Scott;[80] and a large reservoir at Randwick.[81] By 1911 Elliott, Maclean & Co had completed an extensive complex including silos, farm buildings, cottages and a cheese factory, at Thomas Bowling's Arrawatta Estate, Inverell.[82]

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70 *Expanded Metal in Fire-Proof Construction,* p 9; *Some Particulars concerning 'Expanded Metal',* pp 14, 17.

71 J W Pender, drawings the Pender Collection, New South Wales.

72 C E Mayes, *The Australian Builders and Contractors' Price Book* (7th ed, Sydney 1908), p vi.

73 El-Hazouri, 'Reinforced Concrete in New South Wales', p 10.

74 *Building,* I, 5 (18 January 1908), p 53.

75 *Building,* I, 3 (21 November 1907), p 31.

76 Miles Lewis, *Two Hundred Years of Concrete in Australia* (Sydney 1988), pp 12-15.

77 *Building,* I, 1 (September 1907), pp 21-2.

78 *Building,* 16 April 1908, p 72.

79 *Building,* 15 October 1908, p 33.

80 *Building,* 12 February 1909, p 44.

81 *Building,* 15 December 1908, p 44.

82 *Building,* 12 July 1911, pp 58-62.

By 1922 expanded metal had ceased tr be sold by Elliott, Maclean & Co or their successors, and was instead marketed by the Expanded Steel & Concrete Products Co. The original patent had doubtless expired, but this new company dealt in a more general range including reinforcing bars, 'Exmet' brickwork reinforcement, and 'Pudlo' cement waterproofer.[83] In Britain expanded metal was later manufactured by the Expanded Metal Co of Westminster[84] and the Midland Expanded Metal Co of Birmingham.[85]

e. the Kahn bar and the Truscon company

Expanded metal was commonly used in association with the Kahn bar, for which Elliott McLean & Co were also the agents in New South Wales. In 1911 both expanded metal and the Kahn bar were being advertised in Brisbane by Paul & Grey Ltd of Eagle Street,[86] and in Melbourne, Reid Brothers & Co, agents for both products, reported a great deal of work in hand. Both products were used in the dome of the Public Library, and in the new Melbourne Hospital buildings.[87]

The Kahn bar had been patented in the United States by Albert W Kahn in 1902,[88] and exploited by the company which he and his brothers had established, the Trussed Concrete Steel Company, of Detroit.[89] The patent was subsequently assigned to the Trussed Concrete Steel Co. It was a square bar rolled with flanges on diagonally opposite corners, which were subsequently slit longitudinally to allow strips to be folded out. When used in a beam these strips were successively angled up on a slope to serve as shear reinforcement, but in a column they might be bent at right angles to the bar and wrapped around the reinforcement as ligatures. These bars were advertised in the United States in four sizes:[90]

side of square bar		**thickness of flange**		**overall width across flange**	
1/2"	[13 mm]	1/8"	[3.2 mm]	1 1/2"	[38 mm]
3/4"	[19 mm]	3/16"	[4.8 mm]	2 3/16"	[56 mm]
1"	[25 mm]	1/4"	[6.4 mm]	3 3/4"	[95 mm]
1 1/4"	[32 mm]	1/2"	[6.4 mm]	3 3/4"	[95 mm]

The youngest brother, Moritz Kahn, who was an engineer, was sent to England in 1905, and attracted the interest of the firm of Holland & Hannen. The result was that an English company was formed, with just over half the shares held by the American

83 *Building*, 22 October 1922, p 123.
84 Oscar Faber & H L Childe [eds], *The Concrete Yearbook 1949* (London 1949), pp 996-7.
85 Faber & Childe, *Concrete Yearbook 1949*, p 1007.
86 *Building*, 12 September 1911, p 31.
87 *Building*, 12 September 1911, p 23.
88 *Concrete*, I, 1 (March 1904), p 30.
89 Trussed Concrete Steel Co Ltd, *Selected Illustrations Typical of over 10,000 Important Structures built Kahn System of Reinforced Concrete* (Westminster 1934), p 5.
90 *Concrete*, I, 1 (March 1904), p 30.

company and the balance by members and associates of the Holland and Hannen families. It was incorporated on 12 March 1907, and took over contracts which had already been negotiated by Moritz Kahn.[91] In 1909 the American company developed 'Hi Rib' reinforcement, and in 1911 the British company license Joseph Sankey to manufacture this. After a year Sankey gave it up and the British were forced to import Hy-Rib from the United States until they could establish their own manufacturing operation.[92]

It was in the nature of things that the British company would handle the whole Commonwealth market, including Australia. But here there was not the multiplicity of competing systems that was found in Europe, but a near monopoly held by the Monier Company and vigorously defended by John Monash. The editor of *Building*, G A Taylor, was a great protagonist of reinforced concrete, and in 1902 had invented his own (wholly impractical) reinforcing system.[93] He subsequently campaigned against the attempted Monier monopoly, and Victoria especially saw a flood of overseas patents introduced by local hopefuls. Monash maintained a file 'Ferro-Concrete Opposition' in the years 1905-6.[94]

The most significant confrontation involved the main reading room of the Melbourne Public (now State) Library, where Monash's monopoly was successfully challenged by the Trussed Steel Company of England (Truscon). The drawings for the dome of the Public Library from the latter half of 1910 are signed by Truscon's chief engineer in London, Nick K Fougner, while the drawings for the rest of the reinforced concrete, mostly of 1907, appear to have been prepared locally - if not by the architects Bates, Peebles & Smart, then possibly by Truscon's local agents.[95] Although the English company had been directly involved in the library contract, their Kahn bars had made an appearance in Australia at least by 1907,[96] and were sold in Sydney through Truscon's 'advisory agents for Australia', Elliott McLean & Co, who were also the were also agents for expanded metal, and subsequently through separate agents in the various states.[97] The same nexus occurred in New Zealand, where Kahn bars and expanded steel were used in Wellington's first reinforced concrete building, the Sefton Warehouse in Panama Street, of 1907.[98]

After the Melbourne Public Library contract the English Truscon company seems to have continued its Australian presence. Although Elliott Maclean & Co of Sydney were still advertising in 1911 as agents of the Trussed Concrete Steel Co,[99] in 1912 the company itself advertised the Kahn system (including Kahn bars, Hy-rib and Rib-

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91 Trussed Concrete, *Selected Illustrations*, pp 7-8.

92 Trussed Concrete, *Selected Illustrations*, p 9.

93 *Building, Engineering & Mining Journal*, 24 May 1902, p 158.

94 For the period 8 February 1905 to 20 August 1906: file 412 in the Monier records held by John Thomas of Kew, Victoria..

95 Bates, Smart & McCutcheon Collection, Melbourne University Archives, 3.14. The earlier drawings are initialled 'J.A.L.'

96 Walter Jeffries, *The Australian Building Estimator* (Sydney 1907), p 41.

97 C E Mayes, *The Australian Builders & Contractors' Price Book* (7th ed, Sydney 1908), p vi.

98 Geoffrey Thornton, *Cast in Concrete* (Auckland 1996), p 115.

99 *Building*, 12 March 1911, p 18.

Bars) in Sydney in 1912 over the name of its engineer Charles H Reed.[100] The Melbourne agent in 1913 was George Russell Pty Ltd,[101] and a reference to 'KM' bars and mesh used in 1918 in the concrete of a house at Mornington, Victoria,[102] may also mean the Kahn system. By 1922 Elliott Maclean & Co had become the E C Elliott Company Limited, under E C Elliott, and though they were no longer agents for Kahn bars or expanded metal, they were at pains to impress upon the public that they still designed reinforced concrete and supplied reinforcement as well as installing concrete flooring and stocking concrete mixers and Neponset roofing products.[103]

Whilst the Kahn bar itself was a somewhat bizarre device, and was probably a genuinely cost-effective solution in few situations (perhaps only in some heavily-loaded beams where shear stress was a major consideration), the 'Kahn system' was surprisingly durable. This was probably for two reasons - effective international marketing, and the acquisition of other patents, rights and inventions. Expanded metal soon ceased to figure in Truscon's marketing, for it had passed to the Expanded Steel and Concrete Products Co, as discussed above. But by 1913 the Kahn System was advertised as incorporating (though not by name) A-G Considère's *béton fretté* ('hooped concrete), 'Hy-Rib' reinforcement, and the Johnson 'corrugated' bar,[104] all of which were originally separate developments and are discussed as such below. By 1930 the Kahn bar had virtually ceased to be used even in the reinforced concrete designs of the British Truscon Company, and in 1936 its manufacture was discontinued.[105]

f. reinforcement systems

The design of reinforced concrete in the period of competing systems was somewhat haphazard. In 1894 Edmond Coignet and N de Tedesco had published the principles of the modular ratio method, which was to remain valid and in use for most of the twentieth century,[106] but the picture was clouded by the range of competing proprietary systems. Regulations were developed only slowly, and there were none applicable in Australia at the time when reinforced concrete was first introduced. Essentially, in Australia, the Hennebique system was unknown, but the Monier, the Kahn, and - so far as it can be regarded as a system - the Considère system were in competition. Turner's mushroom slab was really a specialised form rather than a complete system, and other special products like expanded metal, and mesh of various sorts, were not suitable for the reinforcement of complete structures.

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100 *The Salon*, I, 2 (September-October 1912), p viii. Howard Tanner, 'Early Reinforced Concrete Frame Buildings in Sydney' (BArch Architectural Science Thesis, University of Sydney, no date), dates the first establishment of the Trussed Concrete Steel Co office under Reed to this year.

101 *The Architectural Students Annual* (Melbourne 1913), p xv.

102 Paul Roser, 'Concrete House in Victoria 1900-1940' (Graduate Diploma in Planning & Design [GDPD, University of Melbourne, 2000), p 8.

103 *Building*, 12 October 1922, p 44.

104 Trussed Concrete, *Selected Illustrations*, no page.

105 Trussed Concrete, *Selected Illustrations*, p 61.

106 E Coignet & N de Tedesco, *Du Calcul des Ouvrages en Ciment avec Ossature Métallique* (Paris 1894), cited in M N Bussell, 'The Era of the Proprietary Reinforcing Systems', in Newby, *Early Reinforced Concrete*, p 187.

One development from the idea of expanded metal was 'herringbone' lathing. In this type the sheet was punched with parallel rows of fairly long slits slanting in alternate directions, rather than with a staggered pattern. When it was pulled apart this gave a rather open herringbone effect, instead of a diamond pattern. The type was listed by Mayes in 1908[107] but had been used earlier, and it can be seen where the concrete has spalled at 2 & 3 Oliver Lane, Melbourne.

The London firm of R Johnson, Clapham & Morris Ltd had been manufacturers of wire netting, wire lathing, and colliery screens, all of which they showed at the Centennial Exhibition in 1888-9,[108] and from this base they developed their own system of reinforcement. Johnson's wire lattice system of reinforcement' was advertised in Melbourne by Chas Dobson Franks & Co by 1908,[109] and in Sydney and Perth it achieved some degree of acceptance before the Great War, having been used for the floors of the Commercial Travellers Building,[110] Ocean House, the Glaciarium, the Police Offices extension, University Medical School, all in Sydney, and for the Mount Lawley Sewer in Western Australia. It was claimed to be 'absolutely true to scientific principles', with the wires running on the direct line of tension so that there were no angles of stress. Lighter wires ran transversely. It was manufactured in both cities, and allegedly approved by the governments of all states and of New Zealand.[111] Although Johnsons had offices in both Sydney and Melbourne by 1911, Dobson Franks also continued as agents.[112]

Lassetter & Co of Sydney advertised as sole agents for 'Triangle Mesh Concrete Reinforcement', the merits of which seem slight. It appears to have consisted of parallel wires crossed by diagonals as 60º and 120º angles to create a mesh of equilateral triangles.[113] The purpose of tension reinforcement at these angles is unclear and, if we are to believe Johnson Clapham Morris, the fact that these wires were twisted around those which they crossed, also weakened them in tension. In fact there is not much to distinguish this material from fencing mesh, and no evidence of its use has come to light.

In 1910 James Nangle reported to the Institute of Architects of New South Wales on a test of a four inch (100 mm) concrete slab reinforced with 'Clinton Electrically Welded Reinforcing Fabric'.[114] This was the product of the Clinton Wire Cloth Company of Clinton, Massachusetts,[115] who held patents on the method of manufacture, and by 1911 it was claimed that the mesh was used in the flooring of

107 Mayes, *Australian Builders Price Book* (1908), p 234.
108 Centennial International Exhibition 1888-1889, *Official Record* (Melbourne 1890), p 467.
109 *Cazaly's Contract Reporter*, XXIV, 25 (23 June 1908), p 97.
110 By Robertson & Marks, *Building*, 15 January 1909, p 43.
111 *The Salon*, I, 1 (July-August 1912), advertisement p x; *Building*, 12 October 1911, p 12; C E Mayes, *The Australian Builders & Contractors' Price Book* (8th ed, Sydney 1914), p 103.
112 *Building*, 12 December 1911, p 38.
113 *The Salon*, I, 2 (September-October 1912), advertisement p x.
114 The fabric was of 6 and 10 gauge wires spaced at 2 and 12 inches (51 and 305 mm). *Art and Architecture*, November-December 1910, p 187, quoted by L J Dockrill, 'James Nangle Architect Astronomer Educator' [5 vols, BArch, University of New South Wales, 1975], IV, p 624.
115 *'Sweet's' Indexed Catalogue of Building Construction* (New York 1906), pp 96-103.

90% of the tall buildings in New York. The British patent rights were acquired in 1910 by Hall & Pickles, who also bought the British Reinforced Concrete Engineering Company,[116] and soon exported to Australia. In 1915 BRC's Australian representative was B F Cox of Melbourne, and the company was advertising both Clinton and Paragon reinforcement. They were able to cite departments of the Commonwealth, Victorian, Queensland, South Australian and West Australian governments amongst their customers.[117]

In the United States another electrically welded mesh was manufactured in the 1920s by the National Steel Fabric Co, a subsidiary of the Pittsburgh Steel Co,[118] but this type is not known to have reached Australia. Another product, 'Triangle Mesh Concrete Reinforcement', which looked rather like wire netting, was advertised in 1912 by F Lassetter & Co of Sydney as sole agents.[119] This was a product of the American Steel and Wire Company, made of cold-drawn steel wire with longitudinal wires at four inch (102 mm) centres, tied around with diagonals in two directions at four or eight inch (102 or 203 mm) spacing.[120] It was used in Hampton Court flats, Bayswater Road, King's Cross in 1922,[121] and by this time S J Dyne & Co of Brisbane claimed to be manufacturing the material.[122] By the 1950s there was another maker of mesh and other forms of reinforcement, Ovaweld Limited of Brompton, South Australia, a division of ARC.[123]

Competing with the mesh systems and claimed to be much more economic was the 'Johnson' or 'Corrugated' bar, apparently another American invention.[124] Although it was advertised as part of the Kahn system, as discussed above, it seems to have also been marketed independently, and in Australia was advertised by the Indented Steel Bar Reinforcement Co of London. It was sold by a local agent, William Adams & Company of Sydney and Melbourne,[125] and the engineer Arthur J Hart was sent out to William Adams by the British company in 1912.[126] Myles J Dunphy, who was

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116 Brian Ferguson, 'Reinforcement', in Miles Lewis [ed], *Two Hundred Years of Concrete in Australia* (Sydney 1988], p 115.

117 *Building*, 12 February 1915, p 20.

118 National Steel Fabric Co, *National Steel Fabric as Used as used for Reinforcement in Concrete Floor and Roof Slabs* (Pittsburgh [Pennsylvania] 1925).

119 *The Salon*, I, 2 (September-October 1912), p x.

120 American Steel & Wire Co, *Handbook and Catalogue of Concrete Reinforcement* (?Chicago 1908); American Steel & Wire Co, *New York City Tests. Triangle Mesh Reinforcement* (New York 1911); F E Kidder & Harry Parker, *Kidder-Parker Architects' and Builders' Handbook* [18th ed, New York 1931], pp 998, 1001.

121 Tanner, 'Early Reinforced Concrete Frame Buildings', p 10

122 *Architect and Builder's Journal of Queensland*, September 1922, no page, reference supplied by Michael Kennedy.

123 F W Ware & W L Richardson [eds], *Ramsay's Architectural and Engineering Catalogue* (Melbourne 1954), § 8/3.

124 The St Louis Expanded Metal Fireproofing Co was advertising corrugated bars in 1904: *Concrete*, I, 1 (March 1904), p 29. By 1906 it had become the Expanded Metal and Corrugated Bar Co: Expanded Metal and Corrugated Bar Co, *Corrugated Bars for Reinforced Concrete* (St Louis [Missouri] 1906), cited in Elton Engineering Books, *Catalogue Number 10. Two Hundred Books on the Engineering of Architecture* (London 1995), p 47.

125 C E Mayes, *The Australian Builders & Contractors' Price Book* (7th ed, Sydney 1908), p 77; ibid (8th ed, Sydney 1914), advertisement p 7.

126 Tanner, 'Early Reinforced Concrete Frame Buildings', p 2, dates the establishment of an office under Hart to 1912.

engaged as his assistant, describes Hart as the first Australian practitioner in reinforced concrete engineering, though it seems unclear to what extent, or at what point in time, Hart established a practice independent of the Indented Bar Company. He did, however, design wheat silos, marine works, bridges, culverts, tanks, cold stores, tall stacks and other structures in the three eastern states. He died in 1920 and the practice was continued by the civil engineer A S Macdonald.[127] A prominent building reinforced entirely with indented bars and supervised by Macdonald was the Astor Flats, Macquarie Street, Sydney, of 1921,[128] and the bars were still being advertised by William Adams & Company in 1926.[129]

Isteg Reinforcing Steel seems to have made a late appearance on the local scene, advertised in 1949 and again in by Edward Campbell & Son, sole manufacturers in Victoria and South Australia. Each piece consisted of two ordinary bars twisted together. The overall length remained unchanged, which meant that the actual length of each twisted bar was increased but the total cross-section of steel remained the same as that of the two bars prior to twisting. It was claimed that the process involved strength testing of each bar and the removal of mill scale, and that the resultant shape so enhanced the bonding that any need for hooks and over-lengths was eliminated.[130]

There were also at least two major systems of steel lathing. 'Hy-Rib', so called from the 3/4 inch [19 mm] ribs which gave it rigidity,[131] was produced by the Truscon company, first in the United States and then in Britain, but marketed in Australia by the British Trussed Concrete Steel Company, a discussed above. There was later a separate Hy-Rib Sales Company, but as it was located in Truscon House, London, it was probably a Truscon subsidiary.[132] 'Key-Lock' steel lathing was manufactured under Macintosh's patent, and sold in Sydney from 1908 by the Interlocking Steel Lathing Company.[133] A lighthouse was built for the Sydney Harbor Trust in 1908 using this system.[134] It was tested at Sydney Technical College in 1910,[135] and advertised by the Interlocking Steel Lathing Co Ltd of 33-5 Sussex Street, Sydney.[136] This was not the same as the 'Keylok' lathing of the Genfire Steel Company, Ohio, a

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127 Myles J Dunphy to Professor Gareth Roberts, 19 May 1977 (files of the Cement and Concrete Association of Australia).

128 Tanner, 'Early Reinforced Concrete Frame Buildings', p 10.

129 *The South Australian Building & Allied Trades Directory and Handbook* (Adelaide 1926), p 13.

130 F W Ware & W L Richardson [eds], *Ramsay's Architectural and Engineering Catalogue* (Melbourne 1949), § 8/2; *Ramsay's Catalogue* (1954), § 8/1. See also Faber & Childe, *Concrete Annual 1949*, pp 1002-3.

131 El-Hazouri, 'Reinforced Concrete in New South Wales', p 8.

132 Faber & Childe, *Concrete Annual 1949*, pp 1044-5.

133 *Building*, I, 5 (18 January 1908), p 75; 16 April 1908, pp 74-6; 11 November 1911, p 109; C E Mayes, *The Australian Builders and Contractors' Price Book* (8th ed, Sydney 1914), advertisements p 34.

134 *Building*, 19 May 1908, p 40.

135 It was used in combination with sixteen no 3 gauge high tensile steel rods, in a six inch (302 mm) concrete slab: *Art and Architecture*, September-October 1910, p 150, quoted by L J Dockrill, 'James Nangle Architect Astronomer Educator [5 vols, BArch, University of New South Wales, 1975], IV, p 621.

136 *Building*, 11 November 1911, p 109, & 12 December 1911, p 36. The advertisement illustrates workers' cottages being built with Key-Lock, probably those carried out by W C Torode in South Australia.

form of diamond mesh lathing,[137] but it does resemble the 'Peninsular Fire-Proof Metallic Lath' being marketed in 1891 by the Garry Iron and Steel Roofing Company of Ohio.[138] The local system apparently consisted of sheets which interlocked at both sides and ends to produce a virtually jointless surface onto which Portland cement could be laid in one coat for walls, floors or ceilings. Our only specific reference to its use is in South Australia.

The transition from a group of competing patent systems to a unified body of reinforced concrete practice was effected in Britain by the activities of the Joint Committee on Reinforced Concrete, which reported in 1907, and again in 1911, and which represented the first official recognition of the material.[139] In France the Commission du Ciment Armé likewise reported in 1907.[140] It is not yet clear exactly when any comparable degree of unity was achieved in Australia.

g. E G Stone & the Considère system

The most innovative form of reinforcement used in Australia was that of the Frenchman Armand-Gabriel Considère (1841-1914),[141] who became Ingénieur en Chef des Ponts et Chaussées in 1883, and Inspecteur Général from 1902 to 1905. In 1906 he formed a company to put into operation his developments in reinforced and hooped concrete [*béton armé* and *béton fretté*], which were then applied to the construction of the viaducts of Avranches and St-Jean de Vesubie, as well as a number of buildings.[142] The basic principle of *béton fretté* was the reinforcement of compression members with heavy spiral reinforcing bars, much heavier than would be necessary for a simple ligature. This was based upon experiments by Considère which showed that this constraint increased the compressive strength of the concrete core. Considère's compression members were usually circular or polygonal in section, and he introduced his spiral winding in other zones of compression, such as the haunches of beams, where they were angled up on the slope.[143] In most respects other than the compression reinforcement, the system derived from that of Hennebique, which was the best-known in France. Hennebique's system was

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137 F E Kidder & Harry Parker, *Kidder-Parker Architects' and Builders' Handbook* (18th ed, New York 1931), pp 1061-2.

138 Garry Iron and Steel Roofing Co, *Garry's Patent Iron and Steel Roofing* (Cleveland [Ohio] 1891), p 26.

139 *B.R.C. Reinforcements* (17th ed, Manchester 1918), pp 124-136.

140 Armand Considère [translated Nathaniel Martin], *The Properties and Design of Reinforced Concrete* (London 1912 [1907]), passim: this is a full report of the instructions, methods of calculation, experimental results, &c, emanating from the Commission.

141 Miles Lewis, *Two Hundred Years of Concrete in Australia* (Sydney 1988), p 18; Miles Lewis, 'Considère en Australie', *Concrete '89 Papers* [Biennial Conference of the Concrete Institute of Australia] (Adelaide 1989), passim.

142 A-M Latour, '(Armand-Gabriel) Considère', in Roman d'Amat, *Dictionnaire de Biographie Française,* IX (Paris 1961), p 490.

143 C G Marsh & William Dunn, *Reinforced Concrete* (London 1905 [1904]), pp 42, 563; A L Colby, *Reinforced Concrete in Europe* (South Bethlehem [Pennsylvania] 1909), pp 46-7; Frederick Rings, *Reinforced Concrete Theory and Practice* (London 1910), p 135; E L Ransome & Alexis Saurbrey, *Reinforced Concrete Buildings* (New York 1910), pp 46-7; Henry Adams & E R Matthews, *Reinforced Concrete Construction* (London 1911), p 259; Peter Collins, *Concrete: the Vision of a New Architecture* (London 1959), p 81.

illustrated by Haddon,[144] but only one probable example has been identified in Australia, a group of farm buildings at 'Golf Hill', near Shelford, Victoria, of the 1920s.[145]

In Australia the greatest individual exponent of the Considère system was E G Stone, as will appear. The basic principle was later taken up not only by the Truscon company, but in some degree by the British Reinforced Concrete Co [BRC], which was formed in 1908, reorganised and expanded in 1911, and had its headquarters in Manchester. There was a Melbourne branch office, which in due course spawned the equivalent local company, ARC. It is unclear what relationship it had with Considère or other patentees, but it clearly stated the Considère principle that 'By [helical wrapping] the strength of the structure is increased to many times what it would be without the hoop or wrap'.[146] Apart from this aspect the BRC system approached, even more than the Monier, what was later to become standard practice in Australia. After World War I the Considère system apparently was marketed by McLean & Morris in Sydney,[147] and it appears that it may have influenced reinforced concrete design in general, and especially in New South Wales.

Edward Giles Stone was a perennial innovator. In 1908 he jointly took out an Australian patent for the construction of fodder storage chambers of rough bush poles.[148] This was followed in 1909 and 1910 by patents in his sole name for the construction of storage chambers in reinforced concrete, and for concrete plate construction.[149] In 1909 he established works at Emu Plains, on land leased from the Emu Gravel Company, and built for the company a five roomed cottage which survives today, on the same panelled system as his silo patent.[150] He built one of his first reinforced concrete silos in 1910 for James Minifie & Co of Kensington, Melbourne.[151] It still stands in Lennon Street, remarkable for the waffle-like pattern of its ribbing, and for its almost futuristic cantilevered headhouse.[152] Meanwhile, in 1910, he built a very large reinforced concrete house at Iandra, New South Wales, for G H Green, MLC, with hollow exterior walls but solid partitions.[153]

The greatest work on the Considère's system, and a truly remarkable one by world standards, was the Dennys Lascelles Austin wool store at Geelong. This building combined many innovations in construction and enormously exceeded the largest

144 Robert Haddon, *Australian Architecture* (Melbourne 1908), pl LVIII.

145 Attributed solely on the grounds of appearance, with haunches, chamfer stopped chamfers &c,.

146 *B.R.C. Reinforcements* [1918], p 13.

147 *Australasian Concrete*, 15 December 1921, p 32.

148 Patent 11,301/1908, Sylvester John Brown & Edward Giles Stone, 22 April 1908.

149 Patent 14,486, 11 May 1909, 'Improvements relating to storage chambers'; 19,054, 19 August 1910, 'Improvements in and relating to building plates and their construction'.

150 Sketch detail of the cottage at 2 Railway St, Emu Plains, and extract from the *Nepean Times*, 30 October 1909, both kindly supplied by Annette Green, 1986.

151 Melbourne City Council building permit application no 2305, 16 November 1910. Stone's address is given as 11 Moore Street, Sydney.

152 Although there is another bank of silos on the site of a more traditional type, the one described is the earlier, and is undoubtedly the one by Stone. Apart from its relationship to Stone's other work, its primacy is established by the fact that a cake was made in the form of the silo to celebrate the firm's 21st birthday, and is illustrated in the *Australian Baker* of 30 July 1927, p 73. This was kindly brought to my attention by Peggy Jones, flour milling historian.

153 *Building*, III (February 1910), pp 73-5.

reinforced concrete roof spans of its day. It was designed by E G Stone in 1909 and built in 1910-11. The top floor, as was usual in such buildings, was the show floor in which wool could be inspected by buyers, and was designed to have as much natural light as possible. It was lit by a sawtooth facing southwards, the trussed window frames and roof panels of which were most elegantly made in precast concrete. These precast sections were slung between a series of parallel trusses, also of reinforced concrete, with a clear span of about fifty-four metres.

Not only was this by a very big margin the largest reinforced concrete roof span in the world, but it was assembled with enormous ingenuity. The great span was achieved by adopting the principles of bridge design, and in fact copying the form of a major bridge at Plougastel in Brittany designed by Considère in his position at the Ponts et Chaussées. Although the bridge was built on the Considère system, other versions were built in France by different methods, so there is no necessary linkage between the concepts. The original bridge consisted of a pair of hogback girders (as distinct from bowstring arches[154]), tied together at intervals, and as used by Stone there were seven equal bays of roofing divided by six such girders tied in pairs - that is, three bridges. The sawtooth panels ran at right angles between the girders.

To describe the structure is not to describe the construction, because the secondary elements - the precast panels - were put in place first, the building was opened and put into use, and the bridge trusses were cast afterwards. The tension reinforcement required in the bottom chord of each truss was so great that a set of overlapping steel plates were used in place of rods, forming a solid piece of rectangular section. This steel element was placed first, upon props, and was given an upward camber to counteract the ultimate settlement. The precast roof elements were assembled in place, also upon props, and the roof completed and sealed. The first wool sale was conducted amongst the props, and when it was over the structure was opened up again to construct the vertical truss members, and the massive spirally-wound reinforcement of the top chord was assembled. After the concrete had been cast in the top chord and the vertical struts, the supporting props were removed, though the rods of the diagonal tension members remained exposed, as did the steel core of the bottom chord. Thus the truss was able to take up its load and settle before the concrete was cast in the tension members. There was no further deflection, and therefore no tension cracks, greatly improving the durability of the structure. The trusses had in effect been pre-tensioned.

Stone went on to design, and with his partner Siddeley to contract for another major structure at Geelong, the sewerage aqueduct over the Barwon River of 1914-15. It is also on the Considère system, and also inspired by an overseas bridge design, but this time the prototype was the great steel Firth of Forth Bridge. The gigantic coat hanger trusses of the bridge are reduced in scale, multiplied in number, modified by reversing their diagonals, and carry an ovoid sewerage pipe. The trusses cantilever 20.7 metres to either side, and the pipe itself spans a further 12.2 metres to meet the next

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[154] Terminology varies, but I distinguish the true bowstring as an arch with a horizontal tie at the base, and otherwise connected only by vertical members. If bracing is introduced it becomes a segmental truss, rather than an arch. If there is a vertical member at the end of this truss, so that the top and bottom chords do not meet at a point, it becomes a hogback rather than a segmental truss.

cantilever, so that the normal centre-to-centre spacing of the piers is 53.7 metres. There are twelve of these spans, one slightly larger one, one much smaller one (to enable two piers to rest on solid ground on Goat Island), and two short spans at either end, making a total length of 756 metres.[155] It is not nearly so beautiful a structure, nor so remarkable in terms of span, technical details or the construction process, but even so it is amongst the noblest feats of engineering in Australia.

From 1910 the Sydney Harbour Trust chose reinforced concrete as the material for floating pontoons at Circular Quay, and in 1912-13 Stone & Siddeley built for the Trust what were believed to be the largest examples in the world, the longest measuring 42.4 metres, with a beam of 12.1 metres and a draught of 2.7 metres. In 1916 the partners entered into a contract with the South Australian Government to build a breakwater at Glenelg for commercial shipping, and a jetty at the remote west coast port of Point Thevenard for the export of primary produce. They had only primitive equipment and were hampered by shortages of materials. Both structures were made of precast caissons, built on the beach, floated out for assembly, and surmounted by precast girders and decking - a task which would be daunting even today.

The caissons were about ten metres in depth and width, while the girders were up to eighteen metres long and thirty tonnes in weight. The caissons were floated into position, upended and sunk, after which timber piles were driven through the temporary bottom diaphragm into the sea bed. The caissons were then ballasted with a fill of weak concrete and boulders, and bridged with the precast girders. The fill concrete that the contractors were forced to use in the arid environment of Point Thevenard was a 1:6:12 mix using beach sand and seawater, and the supervisor reported ruefully that it had not taken its initial set after thirty days. The caisson walls themselves were only 100 mm thick, reinforced with two layers of 6 mm mesh, with a cover of 12 mm, and made of concrete of dubious quality. At Glenelg the contractors were beset by a succession of storms which led to their bankruptcy and to the abandonment of the breakwater project. The caissons still stand, and can be seen at low tide, while the gracefully curved ribs of the wave-reflecting wall now form part of the sea wall at nearby Seacliff. The Point Thevenard jetty was completed in 1920, and has remained in use ever since.[156]

h. W C Torode

In South Australia the builder W C Torode developed his own system or systems, which were not patented, and the details of which are not known. In 1907, the same year as Monash built the first Adelaide building with a reinforced concrete frame, Torode was responsible for two minor buildings using reinforced concrete. He rebuilt Kinderman's Cafe at 13-15 Rundle Street with a reinforced concrete floor and '2 inch thick reinforced cement partitions' (probably based on 'interlocking lathing'). Later

155 See especially Stuart Murray, 'The Sewerage of Geelong', *Transactions and Proceedings* of the Victorian Institute of Surveyors, IV (1919), pp 32-43; R T Mackay, 'Sewage, with special reference to the Geelong Scheme', ibid, pp 57-70 & plates.

156 Miles Lewis, Dean Pickering & Ian Roberts, 'Marine Structures', in Miles Lewis [ed], *Two Hundred Years of Concrete in Australia* (North Sydney 1988), pp 77-8, 80-81

in the year he built W C Rigby's shop in King William Street with verandah posts which he had cast off site with an 'artistic finish' and cured very carefully. The blocks at the base incorporated a downpipe which delivered water directly into the street channel.

In 1908 Torode built a complete house of reinforced concrete at 34 Unley Road, with walls which were apparently cast in situ, and were made in two leaves with a cavity into which slid the window sashes and fly screens. 'Interlocking steel', which was presumably the lathing previously referred to, and which Torode claimed to be a reinforcement designed for columns and slabs. This material was also used in its own right as a lining to the eaves and verandah, to provide for air movement in the roof. In 1908-9 Torode built three structures at Anlaby Station including a small bridge, which has since collapsed, and a slaughterhouse with concrete walls and expanded metal and concrete columns. In 1909 he built a rather grand two-storey house in Bellevue Place, Unley Park, in which the foundations, walls and ceilings were all said to be of concrete in conjunction with interlocking steel. Pillars for the walls were formed up in the steel, which must have been rather like sheet piling, and concrete cast into them. The walls were again in two leaves with a cavity, and each leaf was reinforced with sheets of perforated steel. A concrete house which seems to be reinforced in this manner is at 52 Clarke Street, Port Melbourne. The walls are apparently all reinforced with two layers of metal, and this reinforcement is exposed in the ceiling above the front door, where an opening serves to reinforce the roof space. It is a single steel sheet, split and pressed out to resemble a basketwork pattern.[157]

It appears that the J C B Moncrieff, Chief Assistant Engineer of the South Australian Railways became interested in Torode's buildings, and that the Railways decided to use it in building more than fifty cottages to the north and south of Adelaide. Torode agreed to sell all the details of his construction method, rather than himself tender for the work. The cottages were built of reinforced cinder concrete using the cinders, sand and clinkers which were already available on site. Torode built a few more concrete houses in his own right, but seems to have picked up little if anything in the way of contracts. However, there are other concrete houses in areas near those which he built, which suggest either that his work was more extensive than can be gleaned from documentary sources, or that other builders followed his example. In particular, the first known work of the Ferro Concrete Co at 475 Fullarton Road is near Torode's non-concrete house of 1904, 'Eastella', and bears some resemblance to it. His own last building works are of stone and are conservative in style, and there are indications that he went bankrupt before finally leaving Adelaide in 1929. He died in Sydney in 1937.[158]

i. H R Crawford

157 Discovered by Trevor Westmore, 1990.

158 John Schenk, 'The concrete houses of Walter Charles Torode', *Architecture Australia*, LXX, 4 (June 1988), pp 65-9.

Hugh Ralston Crawford was granted an Australian patent in 1907 for a monolithic reinforced concrete cavity wall,[159] and built a number of Melbourne houses on this system. Crawford was born in the United States in 1876, but came with his parents to Queensland as a child. He was articled to the Townsville civil engineers and architects Eyre & Munro, and then in 1896 joined the Queensland Government's Bridge Department as a designing engineer, and later became engineer in charge of railway construction. He also appears to have been in India for a time.

From 1906 to 1914 Crawford conducted a private practice in Melbourne specialising in steel and reinforced concrete building. From 1914 to 1919 he was employed by the Metcalf Co. of Montreal in constructing wheat silos for the New South Wales Government. In 1919 he was appointed Consulting Engineer for concrete to the Commonwealth Government. In his Melbourne practice he did much of his work at night, and was an innovative designer who was responsible for silos and other structures as well as those on the Turner system, which are discussed below. [160]

Illustrations survive of two Melbourne houses by Crawford, not otherwise documented or dated. The most problematic is the Paton house at 89 Broadway, East Camberwell, for it has an absolutely conventional Edwardian appearance and appears to have at least an exterior facing of brick. The other, in Mont Albert Road, Canterbury, is again very conventionally Edwardian but is visibly of concrete, and is stated to have hollow external walls in accordance with Crawford's patent.[161] His own house, built in about 1912 at 1121 Dandenong Road, East Malvern, survives and is slightly more interesting in appearance.[162] Another house by Crawford at 150 Winmalee Road, Balwyn, has been reported to me by the owners.[163]

j. flat plate construction

The American flat plate system of C A P Turner was introduced in Melbourne by Crawford just over the road from the Public Library, and at exactly the same time as the Truscon work was proceeding on the latter. The flat plate system had its genesis in United States patents granted in 1902 to O W Norcross, which included:

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159 Australian patent no 9135 to Hugh Ralston Crawford, 6 July 1907, ref *Building* September 1907), p 37.

160 Bruce Nixon (grandson of Crawford), verbal information, 27 August 1988. In what follows I draw also upon photographs which Mr Nixon made available to me in 1988, and other photographs and copies of pamphlets which he subsequently gave to Geoff Lewis, a then employee of David Beauchamp, and which they have kindly passed on to me. From the photocopied pages it is impossible to determine the sequence of pages or even how many pamphlets are represented, much less their dates.

161 Illustrated under construction, and complete, in Miles Lewis [ed], *Two Hundred Years of Concrete in Australia* (North Sydney 1988), pp 26-7.

162 *Building*, 12 November 1912, p 167. Dr D R Macdonald kindly permitted inspection of the house, which has since changed hands.

163 Information ? 1998 from Gillian and Mark Tucker, 9836 3850.

> A flooring resting on separate supports and consisting of concrete with metallic network so arranged therein that the amount of metal will be greatest at the points where the greatest tensile and shearing strains are to be supported.[164]

In 1905 Turner illustrated a proposed system using a concrete column with a flared top and a seven inch [180 mm] slab, and in 1906 he built the Bovey-Johnson building in Minnesota in this way.[165]

The two main ways of designing a flat plate were with 'two way' and 'four way' reinforcement, and the latter, with bars on a diagonals as well as on the rectangular grid, was the basis of Turner's system. From 1906 or earlier Turner took out United States patents for his own variation, known as the 'spiral mushroom system.[166] He took out an Australian patent late in 1906 for a system of octagonal columns, each expanding at the head into an octagonal cone which supported a flat plate slab without beams, but with four-way reinforcing and an additional circular assemblage over the supporting cone.[167] In 1916 the United States District Court ruled the US patents invalid because they infringed those of Norcross. Norcross's patents had never been extended to Australia, and Turner's themselves were not challenged up to the time that they expired by natural effluxion in 1920.[168]

According to David Beauchamp the Turner system was referred to as 'mushroom' construction not because of the flared column heads themselves (which occur in other systems), but because of the flared reinforcement within, in which inclined 1$^{1}/_{4}$ inch [32 mm] radial bars rose at the column heads, and supported circular bars, creating a mushroom shape. This was modified in later works by Crawford, in which the radial bars were horizontal.[169] In fact in the Australian patent, and in local examples, the column heads are not circular and flared but simply angled in the form of an octagonal cone, but they are flared in his American patents and buildings, and this is probably a later development in his thinking It is remarkable that the Lindeke-Warner building of 1908-9 at St Paul Minnesota, believed to be Turner's first, is only a year earlier than the Melbourne example. A number of other American examples are illustrated in Turner's pamphlets, and are probably later than the Lindeke-Warner Building, though only one can be dated, on internal evidence, to 1912-13.[170]

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164 'Flat Slab Reinforced Concrete Floor Construction', anonymous offprint, apparently from the *Proceedings of the Institution of Engineers, Australia* (no date [1920s]), p 2. This was amongst the Crawford material, but it is clear from internal evidence that it is not by Crawford himself, but a rival.

165 C D Elliott, *Technics and Architecture* (Cambridge [Massachusetts] 1902), p 194.

166 'Flat Slab Construction', pp 2-3. This refers to Turner's United States patents of 1908 and 1911, but as his Australian patent dates from 1906, these can scarcely be his first in the United States. Turner's pamphlets refer to US patent nos 985119 and 1003384, but whether these are of the specified dates has yet to be checked.

167 Australian patent no 7296/06 to C A P Turner, 7 November 1906.

168 'Flat Slab Construction', p 3. The date of expiry is consistent with a patent of 1906, as a patent normally endured fourteen years.

169 David Beauchamp, email of 30 March and verbal advice of 1 April 2004.

170 These were the Weicker Warehouse, Denver, Colorado, of 1912-13 (square column and square flared head); the King George Hotel, unspecified location (square column and square flared head); the factory building, Minnesota State Prison, Stillwater, Minnesota (circular columns with circular conical heads); the Commerce Building, St Paul, Minnesota (circular column with no head, but a small transitional ring, made possible by the low floor loading); the Hale &

The Sniders and Abrahams building in Drewery Lane, Melbourne, had first been designed by Crawford in reinforced concrete of some sort with a beam and slab and girder system. It was actually begun in 1908, but in 1909 he decided to change to the Turner system.[171] By mid-1910 Crawford had been appointed Turner's representative for Australasia.[172] At the Sniders & Abrahams building Crawford was faced with a choice. He could conform to the antiquated building regulations which did not envisage fully framed structures, and this would mean building the walls wastefully, as thick as if they were load-bearing brickwork. Or he could await the introduction of the new regulations about to come into force, which did take account of concrete frames, but he would then also be subject to a new control limiting the building height to half the street width, which would halve his building.[173] So he proceeded under the old regulations and built with thick walls - probably hollow, though this cannot be discerned on inspection. He was later to extend the Sniders and Abrahams building by two floors, regrettably in a more elaborate style which does not harmonise with the original.[174]

Crawford appears to have been personally responsible for, or at least to have licensed the construction of, a number of subsequent structures on the Turner system. One example identified from inspection by the engineer Dick Van Der Molen is what became the Rolls Royce Service Centre in the Melbourne suburb of Richmond, which dates from 1912.[175] Others are the Myer Building, 258 Queensberry Street, Carlton, and the Telephone Exchange adjoining St David's Park, Hobart,[176] of which the latter must have been a Commonwealth Government commission. J S Murdoch, Chief Commonwealth Architect, also adopted a version of the system in Australian government buildings such as the Ordnance Store, Leichhardt, of 1917-19, the Commonwealth Offices in Adelaide, and additions to the Adelaide GPO. In evidence to an inquiry in 1919 Murdoch did not specifically name either Turner or Crawford, but said that the system he was using was covered by American patents, and that his department had consulted the engineer who was the Australian agent, and had undertaken to pay the normal royalty for the 'adaptation' of the system in the Leichhardt building.[177]

Kilburn Mnfg Co Building, Philadelphia; a building for the Industrial Building Co, Newark, New Jersey; the Corning Glass factory, Corning, New York; the Con P Curran printing building, St Louis, Missouri; the Bostwick-Braun Hardware warehouse, Toledo, Ohio; the Tibbs-Hutchings Building, Minneapolis; an unnamed bridge in Denver, Colorado, and the Tischer's Creek Bridge at Duluth, Minnesota.

171 *Building*, 11 June 1910, p 60.

172 *Building*, 11 June 1910, p 25.

173 *Building*, 12 March 1909, p 45; 11 June 1910, p 59.

174 Bruce Nixon (grandson of Crawford), verbal information, 27 August 1988.

175 Information from Dick Van Der Molen, 1989. I had ? Bridge Road, but it may have been 560 Church Street, the Rolls Royce address in the 1998 phone book.

176 Photographs of these two buildings under construction, showing the slab reinforcement, are included in the Nixon material.

177 Email from David Rowe, Engineering Heritage Group site, 24 & 25 March 2004. According to Rowe, Murdoch described and advocated the 'mushroom'; system in his evidence to the Commonwealth Standing Committee for the Erection of the Ordnance Store, *Commonwealth Parliamentary Papers,* VI, 1917-19.

With the expiration of the patent in 1920 it becomes impossible to maintain a clear distinction, because of course any engineer could adapt or modify the system. The W D & H O Wills building at the corner of Swanston and a'Beckett Streets, Melbourne, of 1924, is also reportedly on the Turner system, but it is a debased version in which the radial bars run horizontally near the top of the slab, rather than sloping upwards on an angle.[178] The Herald building in Flinders Street is also reported to have been on the Turner system,[179] though it seems that this must be a reference to the 1928 extension.[180] This was described as having 'concrete floors of the spiral mushroom type'[181] for the first time in Victoria, so it was clearly not the Turner system as originally patented, but possibly some later improvement..

The first flat plate construction in Adelaide was claimed to be Hayward's Building, some time around 1920,[182] but it seems more likely to be of the new type which emerged at this time, rather than the original Turner system. The change is exemplified by the Sturtevant & Bedford factory built in Melbourne in the 1920s, with flat plate floors, drop panels, and octagonal columns with octagonal cone heads.[183] The drop panels are new feature, and the building was not on the Turner system, despite its apparent resemblance. It had two way rather than four way reinforcement, and was by a different designer.[184]

Many of the flat plate structures that followed differed from the Turner system in that they contained hollow blocks to lighten them and to reduce the consumption of concrete. Hollow terra cotta blocks never achieved the same prominence in Australia as in the United States. It was principally in that country that the idea developed of using hollow blocks not only to form flat and segmental vaulting between girders, as has been discussed, but to combine them with reinforced concrete until it became the structure, and the blocks themselves were doing no more than lightening the concrete slab, especially towards mid-span.[185] This was to create what was in structural terms a ribbed slab or a waffle slab within the uniform thickness of the plate. One of the first uses of hollow tiles was in the Daily Telegraph Building at King and Castlereagh Streets, Sydney, of 1913-14. This was not flat plate construction, and the principal motivation was to insulate machinery noise from other parts of the building, but although the blocks were simply laid in rows they did create a ribbed slab structure.[186]

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178 Email from David Beauchamp, Engineering Heritage Group site, 23 March 2004, and personal email 30 March 2004.

179 Bruce Nixon (grandson of Crawford), verbal information, 27 August 1988.

180 The original building was described as having secondary girders, which is inconsistent with flat plate construction: *Building*, 1927, reproduced in Allom Lovell & Associates, *Preliminary Comment on the Proposed Registration of the Herald and Weekly Times Building* (Melbourne 1995), p 4.

181 *Herald*, 1 November 1927, p 15.

182 Cumming & Moxham, *They Built South Australia*, p 34.

183 *B R C Reinforcements* (2nd ed, Melbourne 1925), p 164.

184 'Flat Slab Construction', p 2. The writer was the designer of the building, and purported to know of only one other 'flat slab' structure in Melbourne, presumably meaning the Sniders & Abrahams building. The address is given as Park Lane, but it is unclear where this might have been.

185 A number of such systems, some using plaster blocks rather than terra cotta, are illustrated in Frederick Squires, *The Hollow Tile House* (New York 1913), pp 116-135

186 Tanner, 'Early Reinforced Concrete Frame Buildings', p 13, T1.

In 1923 a patent[187] was issued for the Innes-Bell system, a name apparently derived from James Bell & Co, who marketed it, and W R D Innes, the company's works director. It was a flat plate system in which hollow blocks were used in the slab, spaced out so that the concrete in between would create in effect a square grid of beams. Around the column head these blocks were omitted so that the slab was solid or, to look at it another way, a drop panel was created within the apparently uniform slab thickness. The earliest works were in Sydney, and the first important one was the Orwell Garage, Darlinghurst, apparently in 1925. Others included the Black and White Cab Company Station, Moore Park; the Haymarket Post Office; Winn's Limited's premises at both Liverpool and Oxford Streets; and the Australian Bag Factory of Bates (Australasia) Ltd at Rosebery.

Later examples include the Tallis Wing of the Conservatorium of Music, University of Melbourne, of 1926-7,[188] and Jensen House, Swanston Street, Melbourne, by the architect Marcus Barlow.[189] The blocks might be of terra cotta or any other material. Terra cotta flooring blocks were made by the Builders' Roofing & Trading Co of Mitcham, Victoria, under the 'Farware' brand, and the Liverpool Tile & Terra Cotta Co of Sydney, under 'L.T.C.'. 'Fibrolite' asbestos cement blocks were made by James Hardie & Co.[190] By 1933 Australian Gypsum Products Pty Ltd were making Victor-Gypsum Hollow Floor Blocks specifically for use in the Innes-Bell system,[191] and after World War II Australian Gypsum Plaster Industries - apparently a reincarnation of the same company - similarly promoted their Victor-Gypsum hollow floor blocks for the purpose. Their advertisement showed how thirteen storeys of this construction could be accommodated in a building of the same height as twelve storeys of standard post and beam type.[192] By 1955 Australian Gypsum Industries were marketing Victor-Gypsum Beam Blocks, designed not to be used in a waffle configuration but placed in parallel, so as to act as permanent formwork for a series of reinforced concrete beams cast in between them.[193]

The purer form of flat plate construction, in which there is no flared column head or drop panel, but simple columns and a slab of uniform thickness, is a phenomenon of the 1950s. The first identifiable example in Australia is Harry Seidler's Williamson House, Mosman, Sydney, of 1951, by the engineer Peter Miller.[194] The AMP Society Building, West Sydney, followed from 1955, all the ceilings being left off-form.[195]

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187 *Ramsay's Architectural Catalogue* (Melbourne 1949), § 7.2, cites patent no 12,151, though if it dated from 1923 it would in the normal course of events have expired in 1937.

188 By Gawler & Drummond, with slab design by K-M Steel of Richmond. The builders were Clements Langford, and the drawings are in the Clements Langford Collection, Melbourne University Archives, as advised by Anthony Hemingway, 2001.

189 James Bell & Co, *Innes-Bell Concrete Construction* (Sydney, no date [c 1928]), passim. Another patent which may be relevant is that of M S Stanley, described as being 'for hollow-block flooring in multi-storey buildings', and apparently current some time after 1916: Cumming & Moxham, *They Built South Australia*, p 105.

190 W L Richardson [ed], *Ramsay's Architectural and Engineering Specifications [Volume 1]* (Melbourne no date [1934]), p 61.

191 Royal Victorian Institute of Architects, *Journal*, XXXI, 3 (July 1933), advertisement p xxv.

192 *Ramsay's Catalogue* (1949), § 7.2.

193 *Ramsay's Catalogue* [1954], § 7/3.

194 Peter Blake, *Architecture for the New World: The Work of Harry Seidler* (Sydney 1973), pp 250-1.

195 *Cross-Section*, no 34 (1 August 1955), p 3.

The effect is more easily achieved with columns of steel rather than reinforced concrete, as at the Architecture Building, Melbourne University, of 1963-4: here two pairs of steel sections welded to the column at right angles to each other lie within the thickness of the slab, and take the shear at the column head.

k. reinforced concrete houses

Crawford was only one of a number of innovators in concrete house construction, many of them stimulated by an overseas source. In 1908 the local journal *Building* carried a report of the concrete house developed the year before by the American inventor Thomas Edison.[196] Edison believed that mass production of 'cement' houses in lots of a hundred or more at one location would reduce costs dramatically to US $1,200 in areas where sand and gravel were available, allowing their purchase by families on incomes as low as US $550 per annum. This compared with US $10,000 for a timber frame house and US $15,000 for a brick one. A complete house was cast in one piece in a period of six hours, using iron formwork,[197] or, as otherwise reported, in two pours - one for the footings and cellar floor, and one for the whole superstructure.[198] In 1912 Edison himself sent a pamphlet on his 'Edison Cast Concrete House' to John Scadden, Premier of Western Australia,[199] but there is no indication that his invention was taken up in that state or anywhere in Australia.

Reinforced concrete had already made its appearance in domestic architecture under the wing of conservative design, but was soon to inspire more innovative forms. Two domestic examples in Melbourne, both by John Monash and dating from as early as 1905, were a flat roof over the ballroom of 'Raveloe' in South Yarra, and a porch added to the Toorak house 'Chastleton'.[200] The porch was designed by the architect George de Lacy Evans, and is remarkable for its elaborate classical design.[201] On the other hand in 1912 John Monash helped his colleague George Higgins to build a reinforced concrete house[202] of a particularly modernistic appearance, with flat roofs and thin, ribbed walls. This was at 4 Ray Street, Beaumaris, a bayside suburb of Melbourne, but was shamefully demolished in 1999. Somewhat similar in its ribbed appearance, but basically of a more conservative design, is what is believed to have been the manager's house at the Geelong Cement Works, of which nothing is known.[203]

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196 *Building,* I, 5 (18 January 1908), p 43.

197 M H Lewis & A H Chandler, *Popular Hand Book for Cement and Concrete Users* (New York 1911), pp 86-9.

198 John Burchard, 'Survey of Efforts to Modernize Housing Structure', in A F Bemis [ed], *The Evolving House*, vol III, *Rational Design* (Cambridge [Massachusetts] 1936), p 411.

199 'Homes for the People', *Western Australian Mining, Building and Engineering Journal,* 6 April 1912, p 4, cited in Ian Kelly, 'The Development of Housing in Perth (1890-1915)' (MArch, University of Western Australia, 1991), pp 300, 302.

200 Geoffrey Serle, *John Monash: a Biography* (Melbourne 1982), p 154.

201 *Building,* I,4 (14 December 1907), p 41.

202 Serle, *John Monash,* p 179.

203 Information from Paul Roser, 2000. The panelling looks much like timber construction, with vertical ribs at about one metre spacing, and horizontals at the base, sill height, window head height, and the top, all of the same shallow depth. It is at least partly surrounded by a conventional verandah carried on sub-classical columns.

A totally individualistic exercise in reinforced concrete occurred at the Dr Wight house in Kyabram, Victoria, in 1907. It was designed by the owner's brother, the architect and engineer Gerard Wight. The stumps and the verandah columns are formed of terra cotta drainpipes filled with concrete and, it is alleged, steel reinforcement,[204] the nature of which is not known. Structurally it would seem that the columns are almost equivalent to the tubular steel columns of Angus McLean, as discussed below. The banded appearance gives an effect of rustication, or, more specifically, of the so-called 'French Order' invented by Philibert de L'Orme.

E G Stone's house at Iandra for G H Green has already been mentioned, and a house at Chatswood in Sydney, built in 1916-17, also seems also to be of some sort of reinforced concrete.[205] One other of the earlier reinforced concrete houses in Queensland was that built at Ipswich in 1910, to the design of Coutts & Son,[206] but the material never caught on as it did in the south. Other houses were of less distinctive types, but all no doubt more or less innovative. In South Australia Torode was soon followed by imitators or rivals, and in 1909 Cowell & Cowell called tenders for a reinforced concrete house at Dunalan, Wolseley.[207] Other developments remain too shadowy to judge, such as a mysterious report in the 1930s of a 'prefabricated' concrete house which had been built in the Melbourne suburb of Glenhuntly in about 1907.[208]

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204 Margaret S Billings of Kyabram, to the Administrator of the National Trust, Victoria, 3 May 1984.

205 Discovered by Michael McCowage and inspected with him in 1996, by courtesy of Wayne Dempsey (02 9411 5675), whose family acquired it in 1927.

206 *Building*, December 1912, p 641, reference supplied by Michael Kennedy.

207 *Cazaly's Contract Reporter*, 20 April 1909, p 61.

208 The house was reportedly built about thirty years previously in Grange Road, Glenhuntly, and was designed by an architect called Clark: *Age*, 14 September 1907.