8.05 Structural Corrugation

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corrugated iron vaulting

The use of corrugated iron for purportedly fireproof flooring systems dates from 1848, but was uncommon in Australia before the 1870s. The use of metal plates, however, is older. In 1773 a British patent was granted to David Hartley for his 'fire plates', and in 1777 the period of the patent was extended by Act of Parliament to thirty-one years, in recognition of the effort and expense to which he had gone, and the impossibility of his obtaining recompense within the normal patent period (fourteen years, extendable to twenty-one). His system was essentially to wrap all the combustible structural members in sheet metal.[1] It was presumably under the provisions of this patent that William Strutt wrapped the skewbacks of his fireproof mills in this way.[2]

In 1793 the Association of Architects, in London, conducted an investigation into methods of fireproofing. A committee of the whole association, including figures like Sir William Chambers, S P Cockerell, Henry Holland, John Soane and James Wyatt, reviewed Hartley's patent system together with proposals by Lord Stanhope and Henry Wood, and suggestions made anonymously in a pamphlet of 1775. Hartley's and Stanhope's systems were found to be effective, and Hartley's less liable to damage, while Woods's was less effective, but useful because it was a liquid application that could be applied in relatively inaccessible locations.[3]

William Fairbairn's well-known system of vaulted iron plates filled over with concrete has been said to date from 1845,[4] but it appears that he in fact first proposed it in 1854, and had not as yet put it into practice. In any case, he does not appear to have considered the use of corrugated iron. The first such system seems to have been invented in 1848 by the British engineer James Nasmyth. The beams were of I-section, but with a larger bottom flange, and the space between was arched with either sheet or corrugated iron. To the underside of this were rivetted curved stiffeners of angle iron, and below there were

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1 Great Britain, *An Act for vesting in David Hartley Esquire, his Executors, Administrators, and Assigns, the sole Use and Property of a certain Method by him invented of securing Buildings against the Calamities of Fire, throughout His Majesty's Dominions, for a limited Time.* (London 1793).

2 A W Skempton & H R Johnson, 'The First Iron Frames', *Architectural Review,* CXXXI (March 1962), passim.

3 Association of Architects, *Resolutions of the Associated Architects; with the Report of a Committee by them appointed To consider the Causes of the frequent Fires, &c* (London 1793), passim.

4 Pedro Guedes, *The Macmillan Encyclopedia of Architecture and Technological Change* (London 1979), p 102.

horizontal tie rods. The space above was filled with Portland cement concrete, but the spandrels were to have cavities cast in them to reduce the weight, and possibly to be used as ducts for ventilation or warming.[5] Subsequently corrugated iron became the norm, the stiffeners were omitted and so, in most normal situations, were the tie rods.[6] The London galvanized iron manufacturer J H Porter is said to have invented a corrugated iron vaulted floor system in the 1840s, but it is possible that he was simply producing it, subject to Nasmyth's patent.

The first identified use of this construction in Australia is at the Treasury Building, Spring Street, Melbourne, of 1859-62. Here some parts of the flooring are fireproofed on either Cheyne's or Fox & Barrett's system, as has been discussed above: but elsewhere there is arched corrugated iron sheeting spanning between inverted T joists, filled over with a limey concrete, and then screeded over to a finished floor surface.[7]

An American patent for the use of corrugated iron and concrete ceilings was taken out by Joseph Gilbert in 1867,[8] though it does not appear to be any advance upon the existing practice in Britain and Australia. By 1872 the full system of I-beams, vaulted corrugated iron and concrete fill (together with ornamental mouldings concealing the base of the joists) is illustrated in the catalogue of the Philadelphia Architectural Iron Company. In February 1868 a committee of the Franklin Institute reported on it, and from this report it appears that Gilbert's patent embraced both straight and curved corrugated sheets, and that the corrugated iron itself was of the standard profile.[9] This can have constituted no advance upon Nasmyth's much earlier patent. Nevertheless Gilbert's proprietorship seems to have been accepted on all sides. A similar ceiling is reportedly illustrated in the *Sheet Metal Builder* of 1875, and may be the product marketed by a licensee or agent.[10]

Already by 1869 Gilbert's system had been used in the First National Bank and other prominent buildings in Chicago.[11] Samuel Nickerson, president of the bank, wrote a testimonial to the system, and it must have been vindicated in the great fire of 1871, for in 1881-3 Nickerson used it in his own house. Today the iron is visible only in a back passage, but apparently it extends throughout the whole building, though concealed by the ornamental ceilings. In 1872 the Philadelphia Architectural Iron Company advertised the system, indicating that the owner of the patent was J S Thorn of Philadelphia.[12] The

5 Thomas Potter, *Concrete: its Use in Building* (new ed, 2 vols, London c 1894 [c 1872]), II, pp 148-9. Potter refers to the inventor as one Naysmith, engineer, of Ebury Street, Pimlico, but I take this to refer to James Nasmyth of steam hammer fame.

6 See, for example, Potter, pp 193 ff.

7 Information from Sue Balderstone, 1994.

8 *Architectural Review and American Builders' Journal*, I (July 1868), p 62, cited in Sara Wermiel, 'The Development of Fireproof Construction in Great Britain and the United States in the Nineteenth Century', *Construction History*, IX (1993), p 19; See Guedes, *Encyclopedia of Architecture and Technological Change*, p 256, for the date of Gilbert's patent: for his forename, the report of the Franklin Institute, *infra*.

9 'Report for the Franklin Institute of Pennsylvania, 26 February 1868', in Philadelphia Architectural Iron Co, *Iron Buildings &c* (Philadelphia 1872), pp 18-19, reproduced in D S Waite [ed], *Architectural Elements* (New York, no date [1972]). See also Mary Dierickx, 'Metal Ceilings in the U.S', *APT Bulletin*, VII, 2 (1975), pp 83-4.

10 Dierickx, 'Metal Ceilings in the U.S', citing *Sheet Metal Builder*, II, 6 (September 1875), p 91 [in the Avery Library, Columbia University].

11 Philadelphia, *Iron Buildings*, p 25.

12 Philadelphia, *Iron Buildings*.

likelihood is that Gilbert had appointed licensees, and that Thorn had acquired limited rights, perhaps only for Pennsylvania.

Examples of corrugated iron vaulting resting on channels occur in South Australia, one if them a house extension by G S Kingston, the dates and details of which are not known to me.[13] Another was the Gladstone Gaol of 1879, where the corrugated iron was covered in concrete, but no further detail is reported.[14] At 'Werribee Park', Victoria, by J H Fox in 1873-8, corrugated iron has been found supporting the balcony floor above the masonry loggia at ground level. Here, and in other such mansions, the principal motive must have been to provide a suitable structure to carry the paved surface above, and fireproofing was probably no more than a secondary consideration. In this instance it is not clear, from photographs of the small area exposed, whether the corrugated sheeting was arched or flat, but probably the latter, as it was supported by transverse iron beams at the mid and quarter points within each bay.[15] Soon there appeared the system of fireproof flooring based upon Traegerwellblech iron, but the use of ordinary corrugated iron continued as well. After Werribee Park, subsequent mansions in Victoria using arched iron included Coiler McCracken's house 'Earlsbrae' (now Lowther Hall) in Essendon, by Lawson & Grey, of 1890-1, and Matthew Davies's house (now Malvern House of Caulfield Grammar School) by Thomas Watts & Son, of 1891.[16] Whether any of these may have used Traegerwellblech iron is not clear.

In Brisbane in 1885-7 Richard Gailey installed corrugated ceilings in all but the basement of the *Courier Mail* Building in Queen Street, using two inches [50 mm] of mortar laid over the top, but no other detail of the system is reported.[17] He may well have used Traegerwellblech, the heavy-duty German iron discussed below. But be this as it may Gailey was not either the inventor or the first to use such a system in Australia, as claimed by Freeland:[18] he was not even the first to use it in Brisbane, for he had been preceded by Stombucco's use of Traegerwellblech at the Opera House. Vaulted fireproof floors appear in Perth at the Treasury of 1892, and at the James Street Boys School and the Supreme Court, the latter having corrugated sheets carried on T-sections. But it is again unclear whether the sheets were Traegerwellblech.[19] The original keeper's quarters at the Jarman Island Light Station, Western Australia, has a novel segmentally arched roof devised by the resident engineer, W L Owen, and consisting of corrugated vaulting carrying a thickness of 150 mm of concrete, allegedly to keep the building cool. It proved unsuccessful, as condensation formed on the underside of the iron and dripped from it, and a conventional pitched roof was carried across the top of it in 1896.[20] The corrugated iron spanned about

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13 Information from Kate McDougall and Carolyn Wigg, 1991, apparently referring to the Orphanage at Goodwood and the Hospital at Gawler, the latter being the former house extended by Kingston.

14 *Australian Engineering and Building News,* 1 September 1879, p 62.

15 Information from David Beauchamp, 1992.

16 John Murphy, who has been architect for modern work on the building, tells me that there is arched corrugated iron carrying concrete in both the verandah and the balcony floors. The original architect's drawings of 2 March 1891 are held by the school, and include a longitudinal section of the verandah in which no arches are visible, so the vault must have run parallel with the house.

17 *Australasian Builder & Contractor's News,* 2 July 1887; 3 September 1887, p 275.

18 J M Freeland, *Architecture in Australia* (Melbourne 1968), p 168.

19 Information from Robin Campbell and Ingrid van Bremen.

20 R & J Oldham, *George Temple-Poole* (Nedlands [WA] 1980), pp 17, 20.

four metres, rested on a reportedly steel, but presumably iron, angle at the wall, and was connected across the centre of each room with a 19 mm horizontal rod and central vertical tie.[21] The iron is reportedly of standard profile, not the deeper Traegerwellblech section.[22]

By 1901 the London firm of G Aston & Son was making a flooring system of lightweight corrugated iron vaulting and concrete between steel joists, but unusual in that terra cotta lintels also ran transversely between the joists at intervals. These were so designed that the top of each was embedded in the concrete, while the bottom was a wide flange sufficient to create a continuous ceiling. This would receive a plaster finish and would thus protect the steel completely from direct access by fire.[23] Interesting though it is, the system is not known to have reached Australia.

development of Traegerwellblech

A heavy form of corrugated iron suitable for bearing loads seems to have been developed in Belgium by the 1870s, and used for bridge construction, but it was not strong enough to be cost-efficient because the corrugations were not deep enough. The idea was then improved upon by Hein Lehmann & Co of Berlin, who invented a machine for corrugating iron plate while cold, and henceforward the material was known by the German name 'Traegerwellblech'.[24] The literal translation of the German was reportedly 'the weight carrying deeply corrugated plate' or 'bearing corrugated iron'.[25] Whereas the section of conventional corrugated iron approaches the form of a sine curve, in Traegerwellblech the tops and bases of the corrugations are semicircular, and they are linked by vertical sections, though this readily apparent only in the deeper forms.

In 1875 the Kaiserhof Hotel in Berlin was burnt, and Traegerwellblech was extensively used in the rebuilding, complete by 1877, for landings, staircases, partition walls &c.[26] It was thenceforward used generally in Germany, especially for the fire curtains of theatres, and the Dutch government ordered gatekeepers' cottages made of it for their colonies. In 1888 Hein, Lehmann & Co showed 'Corrugated-iron, of various kinds', probably including Traegerwellblech, at the Centennial Exhibition in Melbourne.[27]

Something very like Traegerwellblech appeared in Australia in 1881. Schmedes, Erbsloh & Co of Melbourne displayed an 'arched corrugated plate' of 19 gauge [0.35 mm] iron spanning 3.3 metres in an arch rising 300 mm, which carried a substantial load. However there is no mention of Traegerwellblech, which had been tested in Melbourne slightly earlier, nor any indication that common personalities were involved.

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21 H J Stawarz, 'Cossack Task Force, Report on Jarman Island Inspection' [typescript 1987, unpaginated).

22 Information from John Stevens [?Stephens] of Australian Construction Services, Perth, 1992.

23 J E Sears [ed], *The Contractors,' Merchants,' and Estate Managers' Compendium and Catalogue* (15th ed, London 1901), p 150.

24 Peter Behrendt, *Modern Fireproof and Watertight Building Materials* (Melbourne 1883: originally read to the Royal Society of Victoria, 10 May 1883), pp 1-2.

25 *Australasian Builder & Contractor's News*, 6 July 1887, p 133; 27 August 1887, p 251.

26 Behrendt, *Fireproof and Watertight Building Materials*, pp 1-2.

27 Centennial International Exhibition, Melbourne 1888-1889, *Official Record* (Melbourne 1890), pp 423, 736.

Traegerwellblech in Australia

Traegerwellblech was first tested in Melbourne in 1881, using arched sheets of 4, 2.5 and 2 inch (102, 63 and 51 mm) corrugations,[28] and this may have been the same occasion as that when it reported to have been subjected to 'severe tests' before being adopted for the ceilings of the Freehold Investment and Banking Company.[29] By 1883 it was available in Melbourne from Palmer, Scott & Co, as agents for Hein Lehmann & Co, and the engineer Mephan Ferguson had monopoly rights for construction using it.[30] By 1886 it had been used in upwards of five thousand buildings in the world,[31] and it was now being sold in Sydney by Trapp and Elles, of Margaret Street, who displayed some sheets at the Scientific and Mechanical Exhibition of that year.

By now Traegerwellblech had been used for fireproof floors in the City of Melbourne Bank, the Alexandra Theatre, and several 'large buildings' in Collins Street. It had also been used in the Bank of Australia in Adelaide and the Royal Opera House at Brisbane, but not apparently in Sydney as yet.[32] However Trapp & Elles's advertisement in Mayes's price book of that year added to the list the new Fruit Markets in Sydney (later the Corn Exchange), as well as the Hibernian Hall in Melbourne (now Storey Hall, RMIT), and asserted that Traegerwellblech had been used in at least twelve public and private buildings.[33] In 1887 it was used for the Melbourne Storage Company building in Lonsdale Street, Melbourne, which was designed by Behrendt himself, with the architect George Jobbins, and all the ironwork done under separate contract by Palmer, Scott & Co. The strongroom had double walls of Traegerwellblech with concrete in between, the internal sliding doors and the staircases were of Traegerwellblech, and each floor consisted of Westphalian rolled joists with curved Traegerwellblech plates in between, skewbacks of sand and cement, and the balance levelled up with breeze, sand and cement.[34] The Princess Theatre was also built in Melbourne in 1887 using Traegerwellblech, and this is the only reported case in which the name is actually visible as a brand on the iron.[35]

In 1887 Palmer, Scott & Co successfully resisted a move by the Melbourne Chamber of Manufactures to have an import duty imposed upon Traegerwellblech. The customs authorities regarded it as no more than a type of corrugated iron, a category of material which was duty-free.[36] The material reached Australia in fourteen sizes, each either of 3.6 or 4 inch [91 or 102 mm] pitch, and varying from 1.8 to 4 inches [48 to 102 mm] deep, giving a depth to pitch ratio from 50% to 100%, of which the latter is far deeper than for conventional corrugated iron. The thickness was from one to five millimetres, and only

28 *Argus*, 3 February 1881, p 5.

29 Charles Mayes, *The Australian Builders' Price-Book* (Melbourne 1886), p 16.

30 Behrendt, *Fireproof and Watertight Building Materials*, pp 3-4.

31 Charles Mayes, *The Australian Builders' Price-Book* (5th ed, Melbourne 1886) advertisements p xxix. See also p 16 of the text.

32 *Australasian Ironmonger*, I, 7 (1 October 1886), p 164.

33 Mayes, *Australian Builders' Price-Book* (1886), p xxix.

34 *Australasian Builder and Contractor's News*, 26 November 1887, p 464.

35 Information from Robyn Riddett, 1993.

36 *Australasian Builder and Contractor's News*, 27 August 1887, p 252.

some sizes were available curved as well as straight.[37] It was finished with either a varnish or a zinc coating, but not galvanized.[38] It was used most characteristically in the form of arching between girders, and was said to be useful for building 'parabolic' (meaning segmental) roofs, and fireproof staircases, for which the plates were laid on the angle, the risers built on top in brickwork, and timber or other treads placed on them.[39] Commonly it was levelled up with coke breeze concrete, carrying some sort of paved surface. In 1890, when Traegerwellblech as specified for use in the Commercial Bank of Australia headquarters in Collins Street, Melbourne, the fill above was a mixture of coke breeze with little else - actually seven parts of breeze to one of cement and one of sand.[40]

The Sydney agents, Trapp & Elles, seem to have become Trapp & Co, and then in 1889 took in C W Stirling to become Trapp, Stirling & Co,[41] and although it is not so well documented as in Melbourne Traegerwellblech was used extensively in Sydney, and to some extent in the other capital cities. It was probably Traegerwellblech iron, though it is impossible to tell from a photograph, which was used for vaulted ceilings in the wards of Sydney Hospital, presumably dating from the 1890s.[42] In about 1889 John Kirkpatrick had proposed the use of Traegerwellblech and concrete in his competition entry for the Australian Club in Sydney, and it appears that he used this construction in the CML Building, Pitt Street and Martin Place, in 1892.[43] This is not entirely clear, as Irving's survey does not seem to show the corrugated iron as being any deeper than the norm.[44]

Traegerwellblech construction shared the disadvantage of the Dennett and Wilkinson systems, that the bottoms of the metal girders were exposed to fire, and within a decade or so the system seems to have been entirely superseded. The fact that the bottom flanges of the joists were exposed to fire was a weak point of both Dennett's and Wilkinson's systems. The encased columns are reminiscent of those at the Treasury, though the girders are not. It is not mentioned in Nangle's *Building Practice* of 1900,[45] Jeffries's *Building Estimator* of 1907,[46] Mayes's *Price Book* of 1908,[47] or Haddon's *Australian Architecture* of 1908,[48] but it as still being advertised in that year by George H Palmer of Melbourne, as the sole agent for Australia.[49] In Britain a very similar system, but with added fire protection, was being marketed by Potter & Co after the turn of the century.[50]

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37 Behrendt, *Fireproof and Watertight Building Materials*, p 9.
38 Behrendt, *Fireproof and Watertight Building Materials*, p 4.
39 Behrendt, *Fireproof and Watertight Building Materials*, pp 2-3.
40 G W Blackburn, 'The Commercial Bank of Australasia Limited New Premises, &c' [bill of quantities] (Melbourne 1890), p 6.
41 *Australasian Builder & Contractor's News*, 10 August 1889, p 126.
42 E J Brady, *Australia Unlimited* (Melbourne, no date [c 1915]), p 816.
43 *Australasian Builder & Contractor's News*, 15 June 1889, p 550.
44 Emery Balint, Trevor Howells & Victoria Smyth, *Warehouses & Woolstores of Victorian Sydney* (Melbourne 1982), p 106.
45 James Nangle, *Australian Building Practice. Part I* (Melbourne 1900).
46 Walter Jeffries, *The Australian Building Estimator* (1907).
47 C E Mayes, *The Australian Builders & Contractors' Price Book* (7th ed, Sydney 1908).
48 R J Haddon, *Australian Architecture* (Melbourne 1908).
49 *Cazaly's Contract Reporter*, XXIV, 25 (23 June 1908), p 87.
50 Potter & Co's 'A' type floor was made with steel joists, segmental corrugated iron vaults, and concrete. However the lower flange of the joist was encased in sections of fireclay, and below it, at least in the available illustration, was a complete plaster ceiling on expanded metal lathing. P R Strong, 'Fire Resisting Construction' in G A T Middleton [ed], *Modern Buildings* (6 vols, London, no date [c 1905]), IV p 173.

surviving Traegerwellblech

The best surviving specimen of Traegerwellblech Construction is the Queen's Warehouse, West Melbourne, built in 1889-92 to the design of A J Macdonald of the Public Works Department. The first floor is supported by two rows of cast iron columns, creating three transverse bays. These are spanned by rivetted wrought iron girders. Between the girders spans corrugated iron segmental vaulting of the distinctive deep profile characteristic of Traegerwellblech iron and on top of the iron is coke breeze concrete. On the drawings themselves the corrugated iron is in different parts labelled 'Lysaght's Galvanized Tinned Iron 20 Guage [*sic*]'; 'Heavy Weight ... equal to sample'; and 'Traegerwellblech'.[51] It is not as yet clear whether there are different types of iron in different parts, but it seems more likely that Traegerwellblech iron was manufactured - under licence or otherwise - by Lysaghts, whose depot was very dose to the Queen's Warehouse. In 1902 Lysaght's *Metal Trades Referee* listed 'weight-bearing' Lysaght Orb iron of four inch [102 mm] pitch and $2^{1}/_{2}$ inch [38 mm] depth,[52] and in 1912 there was weight-bearing iron of $3^{11}/_{16}$ inch [94 mm] depth and $2^{5}/_{8}$ inch [67 mm] depth.[53]

How many examples of Traegerwellblech construction may survive it is very difficult to say. It is likely that some survives in Her Majesty's Theatre, though this has not been reported, and the only fully authenticated specimens appear to be the Hibernian Hall in Swanston Street, now Storey Hall of RMIT; the Princess Theatre; and the Queen's Warehouse, West Melbourne. However, the balconies of the Rialto building are supported on what appears to be Traegerwellblech corrugated iron, though it is not named in the architect's drawing, carrying coke breeze concrete. Both Flinders Street Station and the Railways Administration building in Spencer Street have a vaulted flooring system throughout which is almost certainly Traegerwellblech.[54] Measurements taken of iron at Spencer Street by Public Transport Corporation engineers show it to have a depth of $2^{7}/_{8}$ inches [73 mm] and a pitch of four inches [102 mm], with a profile rather closer to a zig-zag with rounded corners than to a sine curve. Later Melbourne examples include a building at 188-192 Little Collins Street, where the construction is exposed in the ground floor bookshop, and the 1910 extension of the New Zealand Loan and Mercantile Agency Wool Store, off Tennyson St, Kensington.

buckled plates

Traegerwellblech is an exceptional development in that it was taken up in Australia but not, so far as is known, in Britain and the United States. The lack of interest in those countries may have been due to the fact that in those countries the same function was already being

51 Copies of the drawings kindly supplied by Mr Terry Sawyer of Australian Construction Services, 28 April 1992.

52 *The Metal Trades' Referee* (2nd ed, Melbourne ?1902 [1897]), pp 8, 9.

53 *The Metal Trades' Referee* (Melbourne 1912 [1897]), p 9.

54 Information from Mr Alan Pobjoy of the Public Transport Corporation, who has shown me the principal drawings. These clearly show a vaulted flooring system, though not necessarily a Traegerwellblech one. On the other hand it was regularly referred to as Traegerwellblech by Mr Dudley Cook, since retired.

served by buckled plates, whereas these did not reach Australia until after Traegerwellblech had established itself. The engineer Robert Mallet invented what he at first called the *buckle'd plate,* though the spurious apostrophe was soon abandoned in common usage. A flat wrought iron plate was struck between two dies to give it a shallow domed form, whilst retaining the straightness of the edges. The rise of the dome was about a tenth or a twelfth of the breadth, and when the edges were screwed down onto joists it had an enormous bearing capacity. The invention was advertised in the *Builder* in 1856,[55] and it appears that Tupper & Co were the sole licensees and manufacturers.[56] R S Burn reported that a plate made from a three foot [900 mm] square of $^{1}/_{4}$ inch [6.4 mm] Staffordshire iron, with a rise of $1^{1}/_{4}$ inches [32 mm] would crush under nine tonnes, but if the edges were riveted or bolted to a solid frame, would carry eighteen tonnes.[57]

By about 1870 the plates were being advocated not only for floors, generally with concrete laid over them, but also for partitions, in which the two faces were formed by buckled plates with the domes inwards, and the space between filled with concrete.[58] By the 1880s a new type, Jones's Patent, were being used in England, and in 1882 these reached Australia and were used in Roberts's Buildings in Collins Street, Melbourne.[59] In 1887 buckled plate was specified for the whole of the underside of the new Falls Bridge over the Yarra in Melbourne.[60] By 1893 the Carnegie Steel Company in the United States was manufacturing a modified form consisting of a single strip of steel containing several buckles.[61] By 1909 the sizes available in the United States ranged from three to five feet [0.9-1.5 m] wide and $^{1}/_{4}$ to $^{7}/_{16}$ inches [6-13 mm] thick.[62]

By the 1890s the favoured decking for bridges, though rarely used in conventional buildings, was a form of troughing introduced by the British firm of Braithwaite and Kirk. This was like giant corrugated iron, a foot [300 mm] in depth, and made up out of flat planes rather than a continuous curve - a horizontal plane at the base of the trough, sides angling up at about 60°, and a horizontal plane at the crest. Each piece as manufactured contained three surfaces, such that when bolted together, facing alternately up and down, they created a continuous giant corrugation.[63] Smaller sections of the same type, $3^{3}/_{4}$ inches [96 mm] deep were being made in America by the Carnegie Company in 1893, known simply as 'trough plates',[64] but it was later known in America as 'Pencoyd Corrugated Flooring',[65] presumably because made at the Pencoyd Iron Works of A & P Roberts & Co. Another form, used in Australia, was 'Lindsay's patented steel fire-proof plates', first used in Australia in 1888 to roof the basement safe deposit of Paling's Building in Chisholm Lane, Sydney. Each unit

55 Wyatt Papworth [ed], *The Dictionary of Architecture* (London 1853-92), sv Mallet's Buckle'd Plate, ref *Builder,* XIV, 17 May 1856; Rankine, *Civil Engineering* (London 1864), p 546.
56 *Yorkshire Post Office Directory* (1857), p 112.
57 R S Burn, *Modern Building and Architecture* (London, no date [c 1870]), p 61.
58 Burn, *Modern Building and Architecture,* p 25 & pl xxxvii, figs 22-7.
59 *Argus,* 28 September 1882, p 5.
60 *Australasian Builder & Contractors' News,* 8 October 1887, plate, no page.
61 F H Kindl [ed], *The Pocket Companion* [of the Chicago Steel Company Limited] (Pittsburgh [Pennsylvania] 1893), pp 157-8.
62 M S Ketchum, *The Design of Steel Mill Buildings* (2nd ed, New York 1909 [1903]), pp 296-7.
63 W H Warren, *Engineering Construction in Iron, Steel and Timber* (London 1894), pp 276-7; see also plate V.
64 Kindl, *Pocket Companion,* p 31.
65 Ketchum, *Design of Steel Mill Buildings,* p 216.

was a trough shaped, $^3/_8$ inch thick and able to sustain 65 tons per square inch [1,000 MPa]. Over the top was laid 450 mm of concrete.[66]

66 *Australasian Builder & Contractors' News*, 8 December 1888, pp 514-5.