1. HERITAGE STRUCTURES NOTES

The following material is a brief review of heritage principles as relevant to courses in the School of Civil Engineering in the University of Sydney. Reproduction of the external references contained herein is covered by the teaching provisions of the Copyright Act of Australia (Part III)). It must also be emphasised that the copyright of the respective items continues to be held by the authors or publishers as clearly indicated and such copyright must be respected, even if free download is encouraged by the authors. IGB

The past several decades have seen a strong trend against the near-automatic demolition of old structures to make way for new ones. Encouragement for this has been the realisation that it is often attractive economically to retain a sound, old structure as the core of a new project and also that there is a heritage component in the old structure that is valued by the community.

Internationally such reuse or adaption of old structures is reputed to account for some forty per cent of the activity of the construction industry and there is no reason to suspect that this figure is materially different in Australia. Some consulting companies that have specialist engineers in this type of work and those construction companies that have built up appropriate working skills report even higher proportions.

Amongst the early recognisers of the heritage potential was the Warren Centre for Advanced Engineering, within the University of Sydney, which devoted its 1990 major project to: “The Economic Recycling and Conservation of Structures”. This brought together at some level more than fifty professionals from the heritage area: engineers, architects, conservators, historical archaeologists &c. One work that was frequently referred to was the 1986 publication of the Construction Industry Research and Information Association (CIRIA): “R111 Structural Renovation of Traditional Buildings” which significantly is still in print.

The motive for action by way of engineering intervention can be generated by a range of objectives. At one end of the scale is the need for the repair of a structure that has great heritage value to the community but which holds out little or no hope of producing any kind of direct financial return. This would be in contrast to an item that ranks lowly on the heritage spectrum but had a relatively sound structure that, with minimal attention, could be a very acceptable cost-saving component of a “new” project. In the local context, it is difficult to avoid mentioning the large number of old warehouses, factories and stores that have been converted to apartments of above-average prices. In between these examples are structures of primarily heritage value that produce significant revenue from tourism.

The first in the “Conservation Compendium” series published in the January 2015 “The Structural Engineer” journal of the Institution of Structural Engineers (UK) contains a thorough statement of the reasons for the conservation of structures and hints at the constraints that could be encountered. This will be found in Section 1A that follows.

In addition to repair and conservation works, heritage engineers are often called upon to assess and certify old structures. This can sometimes be quite challenging, as will be seen in Section 1B.

In Australia it is difficult to proceed in this field without reference to the "Engineering Heritage and Conservation Guidelines" produced by Engineering Heritage Australia of Engineers Australia. This publication may readily be found via:

www.engineersaustralia.org.au/engineering-heritage-australia

Much relevant information is found in computer links to external sources and these are given in the sections that follow. A feature of this subject is that, not only are there many organisations generously willing to allow reproduction of this material, but are eager that it be disseminated to as wide a public as possible in furtherance of the conservation cause. All references in Section 15 and elsewhere in the text are available in or via the University of Sydney Library system.

It would be appreciated if there could be feedback if any of the links eventually are found to be inoperative.

Ian G. Bowie

16/12/'16

Conservation compendium

Part 1: Why keep it? Engineers and the modern conservation movement

This article forms part of the Conservation compendium, which aims to improve the way engineers handle historic fabric through the study of historic materials, conservation philosophy, forms of construction and project examples. Articles in the series are written by Conservation Accredited Engineers. The series editor is James Miller.

James Miller MA, CEng, FIStructE, FICE, Conservation Accredited Engineer, Ramboll

Figure 1
Timber window repairs at Ightham Mote demonstrate decision-making based on retention of original fabric

Many years ago, in the 1980s, the author was looking up at window joinery repairs at Ightham Mote, a 14th century property belonging to the National Trust in the UK. Short sections of oak transom had been pieced into the middle of the frames and short ends of the stiles replaced (Figure 1). They stuck out visually, attracting comment. Why keep the old? Why not just replace whole lengths or even the whole casement? Surely this is better in the long run?

It was a comment that many an engineer might have made. What is dictating such piecemeal work? Similarly, and on a broader scale, why does the professional team opt for such a repair strategy on a major restoration project? How has the building acquired the power to influence such decisions?

Historic fabric exercises power in many built environments that the structural engineer will encounter. London, for example, has masterful icons of a very different scale to Ightham. St Paul's Cathedral is one of the most powerful buildings in England, as the views of it are enshrined in planning legislation across London. Over the years, this has affected perhaps billions of pounds of real estate in terms of restricted development and smaller lettable areas. It influenced, for example, the design of 122 Leadenhall Street, where the slanting facade helps to minimise the impact of protected views from Fleet Street. This is a raw power, the result of long-developed legislation and backed by a strong philosophy that addresses the place of heritage in our society.

Another powerful London icon – and one that is surely controversial to many, engineers and others alike – is the Grade II listed Battersea Power Station (Figure 2). What societal values are being balanced when a building, whose defining chimneys are the very parts that now need rebuilding, is able to exert such influence over development, and for so many years?

This is the first article in a new series covering issues of conservation and restoration. Articles will appear in different sections according to their content. They will in general look not at such headlines as Battersea, but at the detail: timber, ironwork, stone, technologies and methods of construction. The contributors are all Conservation Accredited Engineers, specialists in their field. Elsewhere in this issue (see pages 32–35), Jon Avent, chair of the Conservation Accreditation Register for Engineers (CARE) panel, describes what that accreditation means.

However, this first article seeks to answer – at least in part – the opening question: why keep it?

Historic buildings: can any engineer handle them?

Before looking in more detail at the conservation movement, it is worth reflecting on the goals of such a series. Can any structural engineer engage in 'historic' work – that is, work on buildings protected by heritage legislation? In a sense, the answer is yes, certainly, rather like structural engineers can turn themselves to facade engineering, or fire engineering, or become specialists in computational fluid dynamics. All Conservation Accredited Engineers started life in general practice, but steadily developed a passion and skills that match the demands of listed buildings.

Today, there are conservation accreditation systems in the UK for members of RIBA, RICS and the ICE, as well as this Institution. These systems are referenced by client bodies such as English Heritage, Cadw (Wales) and Historic Scotland, and mandatory for some types of project funding, which establishes qualified practitioners in a significant marketplace with the half-million or more buildings and structures that are listed in the UK.

This series aims to make practising engineers better informed when handling historic fabric, to help them examine their own interest in historic work and to equip them with at least some of the attributes required to become Conservation Accredited.

Modern conservation movement

Why keep it? We keep it because society has placed certain values on the fabric. In the modern context that means that change is strictly gauged and measured through legislation, its mechanisms and custodians, but the origin of that legislation was, at the time, public outcry.

The modern conservation movement in the UK is rooted in the works of theorist and art critic, John Ruskin, characterised by thought developed in works such as *The Seven Lamps of Architecture*, written in 1849. Ruskin was a strong influence on William Morris, a polemicist who helped found the Society for the Protection of Ancient Buildings (SPAB) in 1877. SPAB was reacting in a large part against the perceived desecration of churches and other ancient buildings by architects including Sir George Gilbert Scott; light re-ordering had often turned into very heavy reconstruction.

The founding of SPAB was followed by the passing of the Ancient Monuments Protection Act in 1882. The Act was the first piece of heritage protection legislation in Britain and came after considerable pressure from concerned individuals over the destruction of ancient sites and buildings, considerable resistance from landowners and a good parliamentary fight. The founding of the National Trust in 1895 sealed a period of strong advance for the conservation movement[1].

In the early days the approach was practical and common-sense, exchanging decay and reconstruction for maintenance. William Morris was famous for his phrase that in attending to ancient buildings we should "stave off repair by daily care, to prop a perilous wall or mend a leaky roof". Our contemporary interpretation of this is simple – care for listed historic buildings and structures should be planned, regular and ongoing. They should not be left to rot. Engineers may like renewing things to modern standards, but if we understand the old, then we can learn to keep it and, in doing so, demonstrate to our clients and funding bodies the economy of this. The significance of this philosophy in the context of the sustainable re-use and adaptation of our current existing building stock is not lost.


Figure 2
Battersea Power Station – powerful icon on skyline, but rebuilding of chimneys presents paradox

GETTY

Century of charters

Three important international agreements punctuated the 20th century. The Athens Charter[2] came in 1931 amid the winds of modernism sweeping across Europe. It was tight in vision, though open in its interpretation of what 'historic' might be: "... [the congress] recommends that the historic and artistic work of the past should be respected, without excluding the style of any given period". In other words, we should respect the works of the 20th century as well as the 11th.

The Venice Charter[3] came in 1964 and was intended to draw a wider audience from outside Europe, although in practice the vast majority of attendees were European. Progress being interrupted by WWII, Venice was essentially the next conference to follow Athens and still very much couched in the language of buildings and monuments.

There was a problem with this. The wording of these European protocols sat uneasily with the nature of cultural heritage in some countries, where not so much had been built but which nevertheless had sites of great ancient and archaeological significance, such as Uluru (Ayers Rock), Australia. The Burra Charter[4] was signed in 1979 in South Australia, and recognised this significant difference in its choice of language. It established the word 'place' as standard in the heritage practitioner's vocabulary, transcending the question of whether a site is man-made or not, and 'place-making' became part of architectural usage, as people aspired to create built environments worthy of the very best of the past.

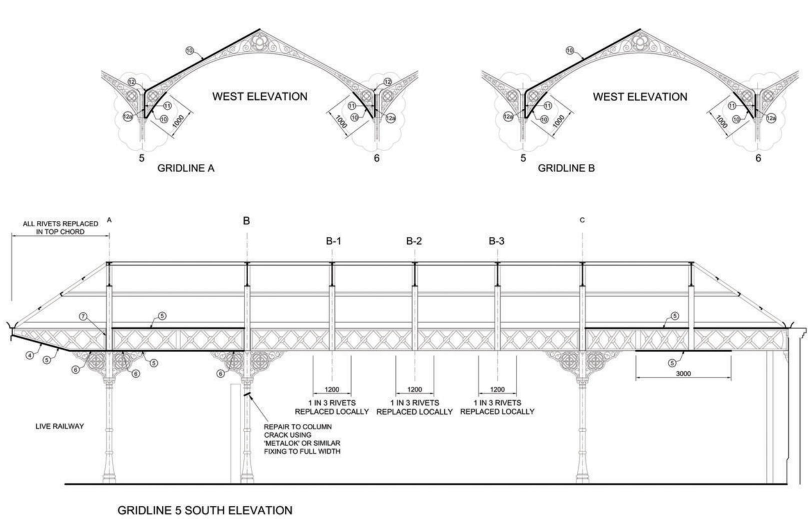
In terms of UK legislation, The Town and Country Planning Act 1947 was the first to introduce a comprehensive listing system to buildings and, thereafter, heritage protection became steadily more powerful. It perhaps reached its zenith in the late 1980s when there was a general sense – a misunderstanding – that protection meant preservation and that all change was bad. The arrival of the Conservation Plan, subsequently the Conservation Management Plan (CMP), and the simpler suites of statements such as the Heritage Impact Assessment (HIA) came never too soon, which bring us to the present day.

Conservation language

Day-to-day conservation in the UK is informed by some of the excellent publications produced by English Heritage, including its guiding *Conservation Principles, Policies and Guidance*[5], which unpack the charters for the practitioner. There also exists the recently revised *BS 7913 Guide to the Conservation of Historic Buildings*[6], which covers similar ground and approaches the subject in a format perhaps more familiar to the engineer.

The skillsets and legislation lead to new terminology which the engineer will do well to learn. Rather like failing to attempt to speak French in rural Provence may lead to inadvertent cultural insult, failing to appreciate the subtleties of heritage vocabulary can give the impression of unsympathetic heavy-handedness or ignorance.

A piece of new work is a 'modern insertion', and together either a repair or insertion is an



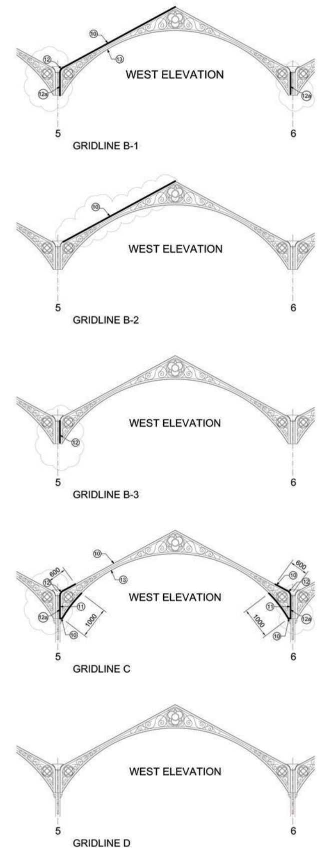


Figure 4
Tynemouth Station canopy restoration. Local repairs were detailed exhaustively after survey, resulting in minimum intervention

'intervention'; the importance in historic terms of each part of the structure is its 'value' or 'significance'; the material of the building is termed 'fabric'; works should be 'sensitive' and one should try not to call a 'sensitive intervention' a refurbishment, as the word can carry – a little unfairly – a pejorative meaning in conservation circles, still echoing with Gilbert Scott's 19th century facelifts. 'Conservation' is today's word and 'preservation' is, in general, yesterday's and not often used. We 'conserve', 'repair', 'restore' or 'reconstruct', with increasing boldness, and these words each have a different meaning.

Conservation principles

Three of the basic tenets of conservation philosophy are minimum intervention, reversibility and an honesty of intervention or repair. An outline of these is found in the *Conservation Principles* defined by English Heritage, with details in BS 7913, but the principles can be traced back all the way through the charters to the 19th century. They can be applied at both macro and micro scales.

Minimum intervention demands that any work to protected fabric is first subject to the test of whether one needs to do any work at all: in the case of a defect – a crack or a sagging timber – whether one can just do nothing and monitor. A number of different interventions should always be offered, and these should be assessed against conservation criteria. Reversibility is a simple test: asking whether the intervention might be taken out at a later date, during another phase in its life, leaving virtually no mark. This is a very good test for building services, which are replaced quite frequently, but it is also true for structural work. An honesty of repair demands that each intervention is true to its generation: not a pastiche, a pretend version of something old, but the very best and most sympathetic of what can be offered in the current age. It must not be brash, but should be something that can be distinguished in future years, and this is sometimes a surprise to the engineer who may be tempted to always copy what is seen.

Figure 3
Bespoke hydraulic site investigation rig made to assist diagnosis of settlement in Westminster Hall. Good diagnosis is pre-requisite to fabric intervention

Examples of conservation philosophy in engineering

The following examples may help to illustrate the application of conservation philosophy.

Westminster Hall

The floor and south steps of Westminster Hall, London, which date from the 1830s, had settled considerably, 220mm in the centre of the flight, causing a trip hazard that had worsened with years. Yet the deeply-founded 11th century hall walls were stable. As a building of huge significance, any intervention would have to be justified by a convincing diagnosis of the settlement. Thus, a major programme of investigation was initiated in 2005, lifting floor slabs by suction techniques and using a purpose-built hydraulic sampling rig (Figure 3) to profile the ground and identify the organic clays responsible – their thickness and disposition. Nothing less would have permitted agreement for the intrusive stabilization works that followed. 'Do nothing' was considered and rejected, as the threat to the fabric remained; instead, a sensitive geotechnical solution was adopted[7].

Figure 5
Iron Bridge, Shropshire. Intervention from 1902, providing greater integrity by tying together lower ends of five arches. In cast iron and mild steel, representing best practice at time

Tynemouth Station

Built in 1882, the Grade II listed Tynemouth Station outside Newcastle had been left to decay for many years as successive attempts were made to establish a long-term future. Parts of the ironwork were in an appalling state. A previous report, in 2007, had incorrectly stated that "the system [of ironwork construction] does not favour selective repair as in masonry and timber construction"[8]. This was challenged by a detailed survey, undertaken by two engineers over two weeks and subject to on-site director review, which established that minor, local repairs could be undertaken instead, carefully locating the areas of decay for cutting-out and specifying the welding of new steelwork in their place (Figure 4). Whole cords were removed on some trusses, but not many. The result is a less costly and far less intrusive solution, with all new elements visible to the trained eye. Intervention has been kept to the minimum[9].

Iron Bridge

The Iron Bridge in Shropshire is both a remarkable example pioneering the use of materials and a global icon. However, like many pioneering structures it has suffered from defects: in this case being highly redundant, unable to accommodate movement in the abutments and now exhibiting over 100 cracks to the cast ironwork (Figure 5). These defects have appeared progressively throughout its life, and each received the attention of some of the finest engineers of their age: probably Thomas Telford in 1801, certainly Sir Benjamin Baker in 1902 and Sir Basil Mott in 1923. What results is honesty, not something hidden or in replica: an authentic patina of alterations and repairs. Although the work predates the modern conservation movement and the development of philosophies, almost all repairs are reversible[10].

Conclusions

Conservation philosophy is something that engineers occasionally struggle with. We are trained to analyse, stabilise and assure. Society expects a chartered engineer to deliver a structure that will not fail; we are schooled to make sure it doesn't and in the past that has sometimes led to heavy, unjustified interventions, to the detriment of our historic fabric.

This series aims to impart knowledge for those practising engineers who are as yet unfamiliar with historic buildings. It will adopt the assumptions of minimum intervention, reversibility, honesty and other principles implicit in conservation philosophy, and to which the individual authors are likely to return to in their examples. Upcoming articles will look in turn at some of the materials of our historic environment: timber, stone and iron, their use and their repair.

References

► 1 Miller J. D. (2011) 'Conservation philosophy in action: examples of structural intervention in the UK and the export of national practices', *12th International Conference on Structural Repairs and Maintenance of Heritage Architecture*, 5–7 September 2011, Chianciano Terme, Italy

► 2 1st International Congress of Architects and Technicians of Historic Monuments (1931) *The Athens Charter for the Restoration of Historic Monuments* [Online] Available at: www.icomos.org/en/charters-and-texts/179-articles-en-francais/ressources/charters-and-standards/167-the-athens-charter-for-the-restoration-of-historic-monuments (Accessed: December 2014)

► 3 2nd International Congress of Architects and Technicians of Historic Monuments (1964) *The Venice Charter for the Conservation and Restoration of Monuments and Sites* [Online] Available at: www.international.icomos.org/charters/venice_e.pdf (Accessed: December 2014)

► 4 Australia ICOMOS (1979) *The Burra Charter (The Australian ICOMOS Charter for Places of Cultural Significance)* [Online] Available at: http://australia.icomos.org/wp-content/uploads/BURRA-CHARTER-1999_charter-only.pdf (Accessed: December 2014)

► 5 English Heritage (2008) *Conservation Principles, Policies and Guidance* [Online] www.english-heritage.org.uk/publications/conservation-principles-sustainable-management-historic-environment/conservationprinciplespoliciesguidanceapr08web.pdf (Accessed: December 2014)

► 6 British Standards Institution (2013) *BS 7913:2013 Guide to the conservation of historic buildings*, London, UK: BSI

► 7 Miller J. D. (2008) 'The diagnosis and arresting of settlement within Westminster Hall in the Houses of Parliament, London', *Proceedings of the 6th International Conference on Structural Analysis of Historic Construction*, 2–4 July 2008, Bath, UK

► 8 North of England Civic Trust (2007) *Tynemouth Station Options Appraisal: Final Report* [Online] Available at: www.northtyneside.gov.uk/pls/portal/NTC_PSCM.PSCM_Web.download?p_ID=18467 (Accessed: December 2014)

► 9 Miller J. D. (2014) 'The restoration of Tynemouth Railway Station canopy', *Proc. ICE Eng. Hist. Heritage*, 167 (3), pp. 136–146

► 10 Heath J. A. and Miller J. D. (2014) 'A history of defects: the Iron Bridge, Shropshire', *Proceedings of the 1st National Conference on Construction History*, 11–12 April 2014, Cambridge, UK


THE ALMONRY OF EVESHAM ABBEY, U.K. – 15th CENTURY

Photo: IGB

2. THE MATERIALS

The first European settlement in Australia brought with it the construction materials then available in the early years of the Industrial Revolution. Eventually domestic production and availability, such as the establishment of foundries and other manufacturers, reduced the reliance on imports.

Prominent materials used in heritage structures were: cast iron, wrought iron, steel, concrete, timber, brick and dimension stone masonry. (The use of the term "masonry" is minimised because different authorities use it to embrace different categories.) With the last two of these materials, consideration must also be given to the properties of the mortar in the joints as an obvious contributor to the strength of the structure and it also is usually subject to deterioration at a greater rate than the main material.

With regard to buildings, Section 2A shows a range of materials in use in the period before the wider acceptance of reinforced concrete in buildings from c1910. In looking at the chart, what must be borne in mind is impact of the severe economic depression that hit Australia in the 1890s which militated against the importation of steel: not produced locally until 1916.

A concise review of the properties of these materials can be found in the previously mentioned CIRIA publication: "Structural Renovation of Traditional Buildings" (690.24 29). There are, however, hazards in the otherwise helpful timeline of use in Figure 1 therein. It must be remembered that the display is for United Kingdom use and there are major differences with that for Australia. As indicated above, the start of use of steel in Australia was deferred for economic reasons. More significantly, the use of hardwoods in Australia started about the time that hardwoods in the UK were shown as finishing and continued well into the twentieth century when scarcity of this resource began to have an impact.

The variety of components in an industrial building and the materials involved can be seen in Section 2B.

The whole of the above range of materials was represented in bridges in the nineteenth and early twentieth centuries. Sometimes, as in the cases of the primarily timber Allan (Section 7D) and Dare type trusses, multiple materials were used: three and four respectively in these designs.

Wider and more economical use of locally produced materials was accelerated in Australia after accurate materials testing facilities became available at the University of Sydney in 1886.

A summary of faults to look for is contained in:

http://www.gsa.gov/portal/content/111478

Overall procedures for structural assessment of existing structures can be found in:

www.peo.on.ca/index.php/ci_id/22608/la_id/1.htm and www.witpress.com/Secure/elibrary/papers/DSHF12/DSHF12006FU1.pdf

Illustrations of defects in steel, concrete and timber structures can be found in: “AREMA Bridge Inspection Handbook”, 2008 (624.20288 6).

DEVELOPMENT OF MAIN BUILDING COMPONENTS, SYDNEY

PHASE		1 TIMBER POSTS & BEAMS		2 CAST IRON COLUMNS & TIMBER BEAMS		3 CAST IRON COLUMNS & WROUGHT IRON BEAMS		4 PARTIAL WROUGHT IRON FRAME		5 PARTIAL STEEL FRAME		6 FULL STEEL FRAME	
PERIOD		1850–1918		1885–1895		1890–1900		1887–1910		1910–1918		1915–1918	
SELECTED BUILDING		JAMISON HOUSE, GEORGE STREET (1D) 1857	24 ALLEN STREET, ULTIMO (1A) 1888		P.M.G. STORE, HARBOUR STREET (2A) 1888	BURNS, PHILP, BRIDGE STREET (3C) 1898+	JOHN TAYLOR BUILDING, PYRMONT (3A) 1893	NATIONAL MUTUAL, GEORGE STREET (4C) 1894	CORN EXCHANGE, SUSSEX STREET (4A) 1887	TRUST BUILDING, C'REAGH STREET (5B) 1913+	NELSON HOUSE, KENT STREET (5C) 190-?	COMM'TH BANK, 120 PITT STREET (6A) 1916	
EXTERNAL SUPPORT	P	STONE & BRICKWORK		NO TYPICAL EXAMPLE OF PRESTIGE BUILDING YET FOUND		STONE & BRICKWORK		STONE & BRICKWORK		STONE		STEEL FRAME	NO TYPICAL EXAMPLE OF UTILITY BUILDING YET FOUND
	U		BRICKWORK		BRICKWORK		BRICKWORK		BRICKWORK		BRICKWORK		
INTERNAL SUPPORT	P	BRICKWORK				CAST IRON COLUMNS		BRICKWORK & CAST IRON COLUMNS		STEEL COLUMNS		STEEL COLUMNS IN CONCRETE	
	U		HARDWOOD COLUMNS		CAST IRON COLUMNS		CAST IRON COLUMNS		BRICKWORK & CAST IRON COLUMNS		BRICKWORK & STEEL COLUMNS		
MAIN GIRDERS	P	HARDWOOD				WROUGHT IRON		STEEL		STEEL		STEEL IN CONCRETE	
	U		HARDWOOD		HARDWOOD		WROUGHT IRON		WROUGHT IRON		STEEL		
FLOOR STRUCTURE	P	HARDWOOD				HARDWOOD		TERRA COTTA BLOCK & WROUGHT IRON		STEEL/CONCRETE		REINFORCED CONCRETE	
	U		HARDWOOD		HARDWOOD		HARDWOOD		WROUGHT IRON & COKE-BREEZE CONCRETE		HARDWOOD		
ROOF	P	HARDWOOD TRUSS				HARDWOOD TRUSS		STEEL		STEEL		REINFORCED CONCRETE	
	U		HARDWOOD TRUSS		HARDWOOD TRUSS		HARDWOOD TRUSS		HARDWOOD TRUSS		HARDWOOD		
STABILITY OF EXTERNAL WALLS *	P	GIRDERS				GIRDERS		GIRDERS		GIRDERS		FRAME	
	U		GIRDERS & FLOORS		GIRDERS & FLOORS		GIRDERS		GIRDERS		GIRDERS		

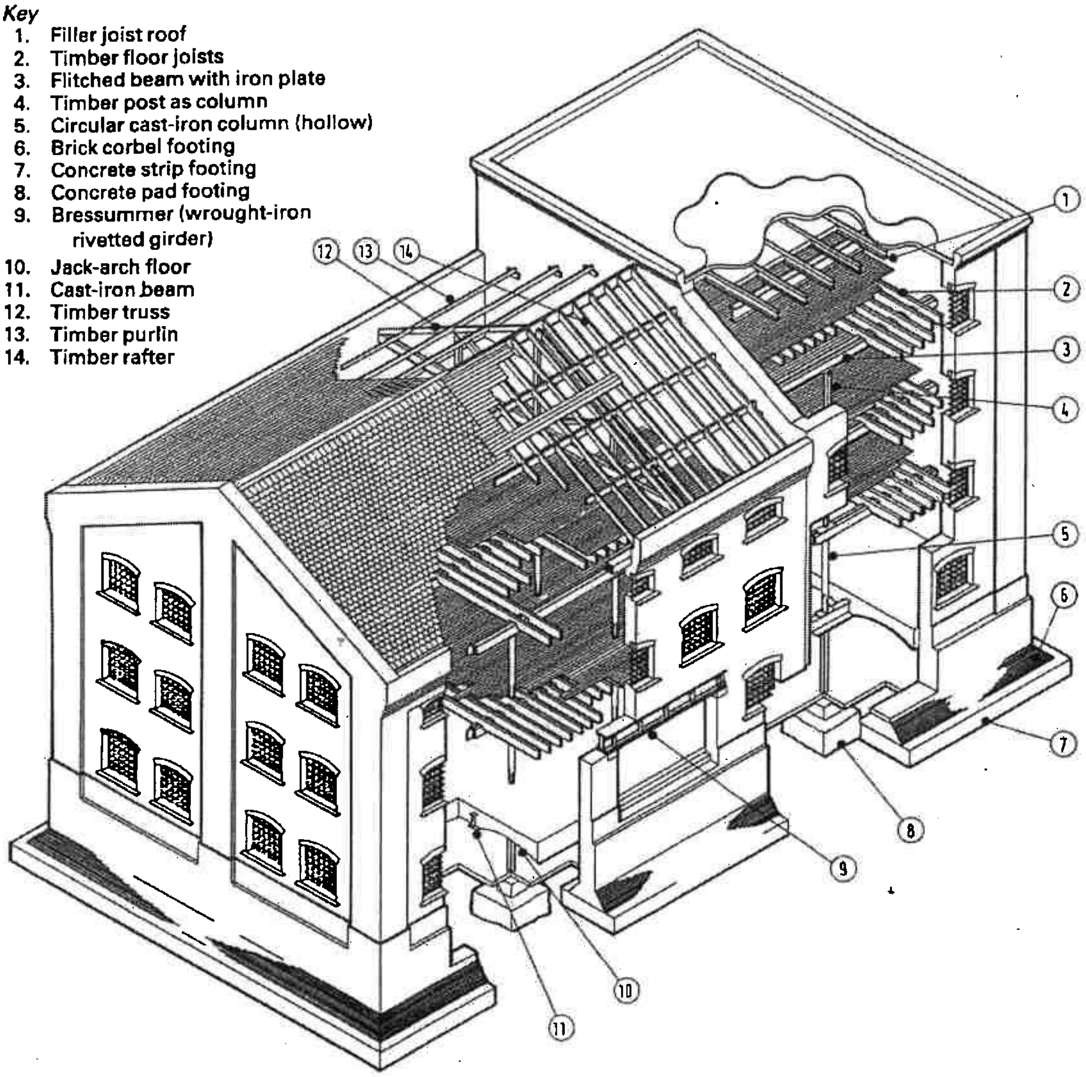
P = PRESTIGE BUILDINGS U = UTILITY BUILDINGS

* IN ALL CASES, CROSS WALLS ARE STABILIZERS

E. Balint: "A Review of Historic Commercial Building Construction in the Victorian Era", 1964.

Key

1. Filler joist roof
2. Timber floor joists
3. Flitched beam with iron plate
4. Timber post as column
5. Circular cast-iron column (hollow)
6. Brick corbel footing
7. Concrete strip footing
8. Concrete pad footing
9. Bressummer (wrought-iron rivetted girder)
10. Jack-arch floor
11. Cast-iron beam
12. Timber truss
13. Timber purlin
14. Timber rafter



Isometric view of typical Victorian industrial building

CIRIA: R111

3. CAST IRON

The use of blast furnaces in the reduction of iron oxides to some form of usable iron results in pig iron. This metal has a carbon content range of from 2.7% to 4.0% but includes a large proportion of impurities. Such a material would have been of practical use in those early societies capable of its production but the arrival of the industrial age demanded a more refined and consistent product. A common method of bringing this about was by a more cautious process of reheating in a "cupola" furnace. This resulted in iron with carbon content in the middle of the above range but still retaining useful quantities of silicon and manganese.

Tests have been carried out on cast iron used in the joint connection units in New South Wales timber truss bridges of a hundred years ago. The carbon content varied from 3.0% to 3.3% with the former material having the slightly greater strength.

This traditional material is referred to as "grey" cast iron in order to distinguish it from later types with improved properties. It should be pointed out that variants of grey iron are still widely used in industry, although much less in civil engineering, as primary components.

Grey cast iron has a compressive strength in the range of 600 MPa to 700 MPa. Its other main characteristic, however, is that its tensile strength is only about one-fifth of the compressive strength. What this means is that manipulation of the second moment of Area of an "I" section in the interests of economy produces a grotesquely large tension flange both in width and thickness.

As well as being a quick identifier of the material used, this section characteristic was put to good use in that that the extra-wide bottom flanges, as in the case of floor joists, can be used as the springing for shallow brick arches between adjacent joists, thereby providing a floor support structure ("jack arches"), as can be seen in items 10 and 11 in Section 2B.

Whilst grey cast iron has a good resistance against corrosion, it has a disadvantage in its brittleness. This made it difficult to cope with the high impact nature of railway loadings as early railway engineers discovered: often the hard way. As well as its attempted use in bridges, cast iron was even used for short sections of railway track rails and the high resulting fracture rate at least had the result of encouraging the larger scale production of wrought iron and the development of rolling mills.

The main success of cast iron was in its use in columns, where the stress is primarily in compression throughout.

Example 1.

Hollow circular columns were widely used as shown in Section 3A, where the example shown is holding up one more floor above. In many industrial buildings, a cruciform cross-section was used.

Example 2.

A more ambitious use of tubular columns is shown in Section 3B. The Carriageworks (Wilson Street, Redfern, Sydney), now an arts and function precinct, has a main building of 15,000 square metres and, along with a slightly larger building of the same construction nearby, were the two main features of a complex constructed in the 1880s by New South Wales railways for the manufacture and servicing of locomotives and other rolling stock. The columns, as will be seen from Section 3B, are arranged in pairs with the taller column supporting the roof of wrought iron trusses and the shorter ones carrying wrought iron plate girders for the tracks of travelling cranes. The columns are fifteen inches (381mm) in outside diameter near ground level with a slight taper in the upper half. Numerous holes drilled in the columns to support factory equipment enabled measurement of thickness of the tube walls to be 41mm.

The old building codes of large cities such as London and New York have tables of permissible loads for a range of standardised sizes of columns, similar to the standard steel section tables in current practice.

On particular hazard in estimating the estimating the capacity of a tubular column is the possibility that the axis of the internal diameter does not line up with the axis of the external diameter due to manufacturing error. This, of course, produces a column that is excessively thick on one side but deficient in strength on the other.

This last aspect and other details of cast iron column design can be found in:

https://sydney.edu.au/engineering/civil/publications/2003/r829.pdf

Some excellent examples of 1869 cast iron columns can be found in the lower concourse of St Pancras Station, London, UK, where compressive tests on the material gave an average strength of 630 MPa.

Example 3.

The High Level Bridge at Newcastle-upon-Tyne in England is a Robert Stephenson design of 1849. It is of double-deck format with a roadway below and an active inter-urban railway of two tracks (originally three) on the upper deck. Its six 38-metre spans are each supported by four cast iron tied arches (visible in Section 3C). Cast iron girders were also used for the road deck, supported by wrought iron hangers, and for girders in the rail deck.

The inevitable deterioration of this structure since 1849 has, perhaps not unexpectedly, affected the main arches – in compression – the least. (The wrought iron tie chains for the arches were attacked by corrosion due to bad drainage, as similarly the wrought iron hangers supporting the road deck from the arches.) Cast iron girders for the road and rail decks which, of course unlike the main arches involve tensile stresses, deteriorated under fatigue and so much remedial work has been required. Fatigue tests have been carried out on some of these girders and strengthening or replacement has taken place. The accumulation of information about the behaviour of cast iron during the refurbishments of recent times has resulted in a more intensive regime of inspection and maintenance.

As a brittle material, is prone to cracks at failure rather than excessive extension as in a ductile material. There is a general consensus against the repair of cast iron by orthodox welding techniques but there are proprietary methods available, developed from technologies used for machinery castings failures.

www.gsa.gov/portal/content/112494 and www.gsa.gov/portal/content/111726

A hazard sometimes found with cast iron is graphitisation, often occurring where there is immersion in or contact with salt water and where there is reaction with the carbon streaks within the iron. An example of this has occurred in the 1874 cast iron piers of the Windsor Bridge near Sydney. Although the bridge is a long way upriver, the tidal cycle of the Pacific Ocean with reduced outflow below dams has gradually increased the saline content. www.rms.nsw.gov.au/documents/projects/sydney-west/windsor-bridge-replacement/windsor-bridge-graphitisation-investigation.pdf

Also see a review of this phenomenon on:

https://www.onlinepublications.austroads.com.au/items/ABC-AAI401-14

The General Services Administration of the USA has a cast iron summary on :

www.gsa.gov/portal/content/111738

and "The Structural Engineer" has a concise ferrous materials summary which is attached in Section 3D. (Note that there is an error in that the boundary between wrought iron and steel is usually taken as 0.1% or 0.08% carbon, not 0.2% as shown in the table on Page 2.) There is also similar information in the early sections of CIRIA C664 on:

www.ciria.org/Resources/Free_publications/Iron_and_steel_bridges_intro.aspx

In deference to cast iron's largest strength component, the compression test on cylinders was long used as a measure but this has now fallen out of favour along with the bend test because of excessive scatter and inconsistency. The preferred test for comparison of cast irons is now the tension test, similar to ASTM A48/A.

MACLEAY MUSEUM, UNIVERSITY OF SYDNEY: CAST IRON COLUMNS, 1887

Photo: IGB

THE CARRIAGEWORKS, REDFERN, SYDNEY: CAST IRON COLUMNS, 1887

Photo: IGB

HIGH LEVEL BRIDGE, NEWCASTLE, ENGLAND: CAST IRON ARCHES, 1849

Photo: IGB

Conservation compendium

Part 3: Historic wrought iron, cast iron and mild steel

This article forms part of the Conservation compendium, which aims to improve the way engineers handle historic fabric through the study of historic materials, conservation philosophy, forms of construction and project examples. Articles in the series are written by Conservation Accredited Engineers. The series editor is James Miller.

John E Ruddy BEng, MA(Conservation), CEng, MICE, MIStructE, Conservation Accredited Engineer and Director, Capstone Consulting Engineers Ltd

Figure 2
Cast iron column, complete with cast Corinthian capital

Figure 1
Repair to corroded steel frame

As structural engineering students, we learn about mild steel, modern design and construction methods. However, historic structures often do not fit into this mould. Whether you work in conservation or are a general practitioner, you are likely to come across cast iron, wrought iron, as well as early mild steel structures. The historic ironwork could be as small as a strap, providing tension across a joint, or more dramatically, the whole structure.

The first major all steel bridge – the Forth Bridge – was famously called "the supremest specimen of all ugliness" by William Morris (co-founder of the Society for the Protection of Ancient Buildings). Yet it went on to become not only listed in the UK (on the Statutory List of Buildings of Special Architectural or Historic Interest), but is currently being considered for designation as a UNESCO World Heritage Site.

Key properties

Cast iron, wrought iron and mild steel are chemically speaking very similar to each other, being alloys of iron and carbon. It is the carbon content which gives them their distinctly separate properties (Table 1)[1,2].

Cast iron

The lower tensile strength of cast iron in comparison to compression is due to the carbon within it. On cooling, the carbon forms into 'plates' of graphite throughout the iron. These plates are able to transfer compressive stresses, but because they are not bonded to the iron they represent planes of weakness under tensile loads. To overcome this issue, cast iron beams, for example, typically have larger tension flanges.

However, the resistance of cast iron to corrosion is excellent. This is partially attributed to the 'fire skin' which develops on the surface of a casting, the fusion of iron and silicon (from the sand mould), during production.

The production process of cast iron greatly influences its properties such as strength, ductility and resistance to fatigue. If a casting cools quickly, the graphite plates do not form, resulting in a stronger but more brittle alloy of iron. Cast iron was specified in terms of the origin of the pigs used, each having its own slightly different characteristics which affected the overall properties. Imperfections incorporated during the casting process act as stress concentrations, lowering the capacity of the section. Due to its brittle nature, cast iron is not suited to rivet connections which are driven through punched holes. Also cast iron cannot be 'welded in the fire' like wrought iron. Connections tend to be mechanical, such as bolts (using cast holes).

Wrought iron

The advantage of wrought over cast iron is that it exhibits ductile characteristics, deflecting under impact and shock loads. Importantly, when overstressed, it gives a clear warning of an approaching collapse by permanently deforming.

Wrought iron is made up of almost pure iron and an inert silicate 'slag' material. The iron is worked, or 'wrought', under heat, lining up the slag layers and iron into strands, which are better able to resist the passage of microscopic cracking. Another consequence of this aligning of slag layers is that wrought iron is weaker in the perpendicular direction to the aligned layers. This is not a problem with wrought iron sections in service, as the process of forming them (by hammer blows or rolling) aligns the iron and slag the right way. However, this is why electric arc (fusion) welding to wrought iron is not advisable.

Wrought iron can be forge-welded together, a process where the two pieces are heated and squashed into one piece under hammer blows, using the slag as flux. Also, as wrought iron is ductile, it can be punched to accept rivets. Wrought iron is more susceptible to rusting than cast iron. The rust delaminates from the body of the iron along the slag veins of weakness.

Mild steel

Mild steel is stronger than wrought iron and also exhibits greater ductile characteristics. This has contributed to it currently being the most widely used structural metal. Connections can be made to steel in a variety of ways. Having no slag, steel is isotropic in strength and can be fusion welded. As with wrought iron, it can be bolted, and its ductility allows it to be punched to receive rivet connections.

Steel readily rusts in atmospheric conditions, and steel therefore needs to be protected, using a barrier such as paint to separate it from the atmosphere.

Development of iron

Wrought iron has been smelted into a bloom from iron ore over charcoal since before 2000BC, primarily to be used for tools and weapons.

Cast iron has been produced in quantity since the invention in the 1300s of the blast furnace, in which the iron is liquefied out of the ore. The molten iron could then be cast into a variety of mould shapes. Various advances were made over the centuries, improving the production process. In the 1860s Bessemer and Siemens invented processes to produce significant quantities of steel cheaply.

The continuous rolling mill invented by George Bedson in 1862 is one of a number of advances in this revolution from small-scale craftsmanship to mass production. With it came improved quality control, so that the material properties could be assumed with confidence. In 1880 Siemens invented the electric arc furnace. As no combustible fuel is present, the steel cannot be contaminated by the combustion products and a pure steel is produced. This heralded the birth of modern structural steel.

Table 1: Key properties of cast iron, wrought iron and steel

Key properties	Cast iron	Wrought iron	Steel
Carbon content (%)	2.5–4.0	<0.2	0.3
Tensile strength	Poor	Good	Good
Ultimate stress (N/mm^2)	65–280	278–593	386–494
Allowable stress (N/mm^2)	24	78	117
Compressive strength	Good	Good	Good
Ultimate stress (N/mm^2)	587–772	247–309	386–494
Allowable stress (N/mm^2)	125	78	117
Ductility	Poor	Good	Good
Young's modulus (kN/m^2)	66–94	154–220	200–205
Corrosion resistance	Excellent	Good	Poor
Fatigue resistance	Poor	Good	Good

The ultimate stress values for the metals were obtained from the 19th century experiments of Hodgkinson, Twelvetrees and others, as described by Swailes[1] and Bussell[2].
The allowable stress values are from the London Building Act 1909.

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Figure 3 Example of cold stitching

Figure 4 Wrought iron strap within 15th century church tower

Examples of repair

Corrosion

Atmospheric corrosion is an electro-chemical process that takes place in the presence of oxygen and water. The reaction transforms the strong useful metal into weak rust. Not only does this result in reduced strength, the rust itself expands as it forms. This occurs with high molecular force, and the forming rust can cause considerable damage to surrounding work, particularly where the iron is built into masonry. A small dowel or cramp can jack up a surprising weight of stonework above it. Where iron plates are riveted together, these forces can be enough to snap the rivets holding the plates together.

Figure 1 shows a steel frame from the early 1900s which was exposed when refurbishing a shop front in Glossop, Derbyshire. The area of steelwork was severely reduced due to corrosion in places, particularly where there had been long-term contact with damp, such as where columns pass into the ground, or close to failing flashings. Here the solution was to dress the area back to sound metal and weld on new pieces to compensate for the material lost, before protecting with paintwork.

Cast iron

A redundant church in Leeds was recently converted into a community performance space. This involved a new infill floor, adding load to the existing slender balcony columns. Unlike modern (and historic) rolled steel sections, these columns were not made to set dimensions. An important step in assessing the load capacity of exiting cast iron columns is finding out how thick the casting wall is. This is done by drilling small holes. Three holes are needed as the void within may be off centre. One of the columns is shown in Figure 2.

Due to the brittle nature of cast iron, fractures can occur. One possible cause can be impact damage, or localised thermal shock. Cast iron cannot be readily welded; however, a mechanical 'cold stitching' technique can be used. This is where nickel-steel stitches are inserted into tight-fitting drilled slots at regular intervals, running across the fracture line, knitting the two sides together again (Figure 3).

Wrought iron

Figure 4 shows a wrought iron strap repair to the bell frame within a 15th century Lincolnshire church. This has been carefully crafted to fit the oak frame. Despite hundreds of years of relative exposure, all that is needed is the removal of the surface rust, followed by painting (although it is suspected that it would manage many more years unpainted).

Conclusion

I am from a 'steel town' and am reminded of that heritage when I see 'Dorman Long' or 'Middlesbrough' stamped on steel sections across the country and across the globe. I have had the privilege of seeing castings being poured at Longbottoms iron foundry near Huddersfield, wrought iron worked in the furnace at the Topp and Co. blacksmith's works in Yorkshire, and steel beams being formed in the rolling mill at Redcar. There is real craftsmanship in iron and steelwork. It is often easier to see it in older structures, and it is this craftsman's input that to my mind gives historic work its 'value', making it worth conserving. I suspect it is recognising and respecting this value in older structures that draws engineers towards 'conservation engineering' as a career.

References and further reading

1) Swailes T (1995) '19th century cast iron beams: their design, manufacture and reliability', *Proc. ICE Civ. Eng.*, 114 (1), pp. 25–35

2) Bussell M (1997) *P138: Appraisal of existing iron and steel structures*, Ascot, UK: Steel Construction Institute

Further reading

Bussell[2] provides further information on uses and dates of iron and steel structures, guidance on analysis and the estimation of load capacity.

4. WROUGHT IRON

The early ironworkers would not, of course, have fully understood the metallurgical changes involved but it was found that, by working and reworking heated cast iron, there was a transformation into a very different product: one that had a tensile strength of the same order of size as compressive and one that had lost its brittleness to become quite malleable and ductile. When this process became regularised in larger production facilities, it became known as "puddling".

What had actually happened was that the working of the material had expelled carbon to the extent of reducing its content to much less than 0.08% and also to introduce a laminar metal structure. Whilst the compressive strength that had been provided by cast iron had to some extent been reduced, it had been overtaken by the tensile strength. The ultimate tensile strength was now in the 300 MPa to 350 MPa range compared with the compressive strength of 280 MPa to 300 MPa. The nineteenth century London building codes give the same permissible working stresses in wrought iron for both tension and compression: 78 MPa.

In view of what was stated in a previous section about cast iron sections, it will be immediately appreciated that it was now possible to produce the very useful "I" sections with the horizontal neutral axis as an axis of symmetry: much more recognisable to the modern user.

One area of engineering that benefited from such developments was that of railway track where short, cast iron sections were replaced by wrought iron flat straps on longitudinal timber bearers and then by a variety of competing rail sections entirely of wrought iron.

The simplest section that the earliest rolling mills could produce was the equal angle and these were used in great profusion to be combined by riveting with flat plates for the production of beams. There was a preference to synthesise box sections as much as "I" sections. These can be detected in Section 3A above the column and in the travelling crane support beams in Section 3B.

The box approach to lateral stability probably had its most eminent proponent in Robert Stephenson whose rectangular box sections enclosed a single railway track as exemplified by the long 1850 Victoria Bridge at Montreal, Canada, the Britannia Bridge and the Conwy Bridge, the last two being in North Wales. Unfortunately, the engineering design of these showed little appreciation of the effects of summer heat and enclosed smoke on passengers. Nevertheless the concept persisted.

Example 1.

Completed in 1867, the Victoria Bridge over the Nepean River (Section 4A) at the western edge of what is now the Sydney metropolitan area, has narrow vertical side box sections as the main structure in its three continuous spans (Section 4B, Figure 4). It was originally designed to carry two railway tracks but, for its first forty years it only had one track plus a roadway. Thereafter it has carried the Great Western Highway and a footpath. Forty kilometres to the south at Menangle, a similar wrought-iron box girder bridge, three years older, still carries two very active railway tracks but has had intermediate piers inserted in recognition of the increased railway loading over the years. The curved longitudinal lines visible on the outside of the spans of these bridges have no structural significance but were allegedly included to reassure the public. The wrought iron for these two bridges was made by Peto, Brassey & Betts in the same works near Liverpool, England, as the material for Stephenson's Victoria Bridge in Canada. Refer to: "The Britannia Bridge and Other Tubular Bridges", Rapley, J., Tempus 2003 (624.21 1).

The search for more economical uses of wrought iron led to the concept of the lattice truss which reduced the amount of material in the web sector, using an arrangement reminiscent of a garden trellis. The earlier phase of this development involved a large number of smaller sections as overlapping diagonals but later eased into fewer diagonals but with greater cross-sections.

Example 2.

The 1886 double-track Meadowbank Railway Bridge in western Sydney shown in Section 4C was the largest and second-last of a series of twelve railway bridges built for the New South Wales railways between 1874 and 1887, ten of which survive. Most of these bridges had multiple spans, with a constant span length of 48.5 metres throughout. The spans were imported from different manufacturers in Britain and one from Belgium.

An interesting design feature is that, where there are three spans or six spans – as in the case of Meadowbank or single-track Como – then they were designed as continuous three-span groups over four supports. The top chords can currently be seen from the deck and the splices in the chords are indeed not over the bridge piers, indicating that the designer was striving to maintain the continuity principle. The curved overhead lateral bracing arches (not to be confused with the later electrification gantries) are a characteristic of this type of bridge.

The bridge carried the main railway line from Sydney to the north from 1886 to 1980 and it has since been converted to a pedestrian and cycle crossing of the Parramatta River. The Como Bridge in Sydney's south also now has this function.

Other elements found in traditional wrought iron besides iron and the small amount of carbon were earlier regarded as impurities but it was later found that they contributed to the very good resistance of wrought iron to corrosion. It is because of this property that wrought iron artefacts, including bridge spans, are sought after for possible re-use if circumstances do not allow them to continue in their original function.

In designing the 1889 Paris tower that bears his name, A. G. Eiffel had the availability of steel but opted for wrought iron in spite of its slightly lower strength but because of its good performance against corrosion. The Forth Bridge in Scotland, constructed of steel, was completed in 1890. The last wrought iron bridges on New South Wales railways and main roads were completed in 1893.

In order to look at the approaches of the original designers to lattice and other structures, it is useful to refer to "Wrought Iron Bridges and Roofs" by W. Cawthorne Unwin (Spon 1869) which has good claim to being the leading textbook of the time on this topic and is on:

https://catalog.hathitrust.org/Record/002018563

also from a number of print-on-demand publishers. This publication also has local interest in that it mentions that the Victoria Bridge at Penrith NSW (Sections 4A and 4B) sustains tensile stresses of 4.75 tons per square inch (73 MPa) and compressive stresses of 4.25 (66 MPa). There is also free download of the paper: "Conservation and Upgrade of Historic Wrought Iron Bridges in New South Wales" by I. Berger and M. Tilley via:

https://www.onlinepublications.austroads.com.au/items/ABC-MHB002-11

More information on the properties of wrought iron can be found in a report on the Menangle Bridge:

www.Pandora.nla.gov.au/pan/43759/20040805-0000/grundyconsultancyreport.pdf

and there is general information on:

www.gsa.gov/portal/content/111770 and

www.environment.nsw.gov.au/resources/heritagebranch/heritage/maintenance31metalwork.pdf

VICTORIA BRIDGE, PENRITH, NSW: WROUGHT IRON BOX GIRDERS, 1867

Photo:IGB

PLATE IV.

THE PENRITH BRIDGE, GREAT WESTERN RAILWAY, AUSTRALIA.

DESIGNED BY MR. WHITTON, GOVERNMENT ENGINEER, SYDNEY, NEW SOUTH WALES.

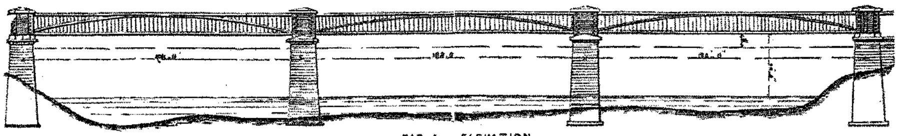


FIG. 1. ELEVATION.

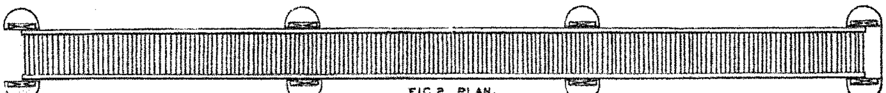


FIG. 2. PLAN.

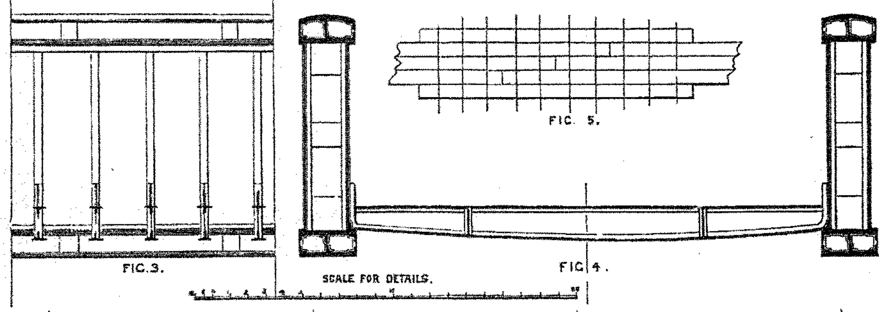


FIG. 3. FIG. 4. FIG. 5.

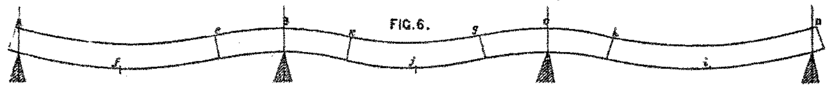


FIG. 6.

Maw, W.H. & Dredge, J.: "Modern Examples of Road and Railway Bridges …", 1872

MEADOWBANK RAILWAY BRIDGE, NSW: WROUGHT IRON LATTICE SPANS 1886

Photo:IGB

5. STEEL

The production of steel does, of course, have a long history but until the middle of the nineteenth century it was a very expensive material to produce. Because of the labour-intensive processes, quality swords and armour were limited to the wealthy.

The eventual perfection of the Bessemer process and its successors meant that the cost of steel production in Europe and North America dropped to a fraction of its previous level and it became available in quantity from the 1880s onwards. Although the early steels were only about twenty per cent stronger than the wrought iron that they were replacing, the cost was not greater by the Bessemer approach. One area where wrought iron still held sway for some years was in shipbuilding where it was detected that steel was slightly more brittle than wrought iron, creating doubt that the flexibility of ships' hulls in bridging large waves might cause disastrous cracking. Whilst this concern was excessive, it did contain an element of prophecy as regards the cracking failures, though for somewhat different reasons, of welded ships half a century later.

Although steel was first produced in Australia in 1900, it was not available in useful quantities for structural purposes until 1915. This meant that all steel used before then had to be imported, continuing in lesser quantities after this date. The costs of international transport were large and thus the importation process was dealt a heavy blow by the severe economic depression in Australia that started in 1892. An example of the effects of these hard times was that they saw the ascendancy for a few years of timber truss bridges, using local hardwoods, over designs that had originally been assigned to steel construction.

Presumably economic conditions had improved by 1905 because this was when the Dare type timber truss replaced the timber bottom (tension) chord of the Allan type truss with a steel section.

The first standard ever issued by Standards Australia: Standard No.A.1 – 1928 was dedicated to structural steel. It included a requirement for an ultimate tensile strength of from 432 MPa to 509 MPa. It also included the surprising statement that the steel it dealt with was not to be used in bridges. Perhaps this was an echo of the "cracking ships" matter referred to above, in relation to a cyclic load. Also included in the standard were tables of beams, angles and channels. The table for beam properties is shown in Section 5A of these notes.

The steel producer Dorman, Long and Company, based in Middlesbrough, England, is widely known as the constructor of and primary steel supplier for the Sydney Harbour Bridge. Less well known is that the organisation's products were extensively imported into Australia in the decades before and after this major project. The name of this company is frequently detected on the webs of steel sections that are exposed such as the supporting columns of service station canopies. The company's regularly published designers' handbooks can be found online. Section 5B of this guide shows the 1906 tables for their I-beams and equal angles as may be encountered in Australia. It will be noted that it includes the fairly popular wide flange 9" x 7", useful in floor structures, which is missing from the Australian standard's list. On the Sydney Harbour Bridge, 12" x 12" equal angles were used extensively by Dorman, Long although these would have been made of their special silicon steel which was a strong factor in their winning the contract which started in 1924.

http://sydney-harbour-bridge.bostes.nsw.edu.au

The carbon content in this mild steel era ranged from 0.13% eventually up to 0.25%, with 0.18% and 0.20% frequently quoted. The ultimate tensile strengths were from 390 MPa to 540 MPa with controlled heat treatment. The safe load tables for girders are said, in 1906, to be calculated from an extreme fibre stress of 116 MPa. In the 1924 Dorman Long handbook, this had increased to 124 MPa. In 1910 Professor W. H. Warren reported that the working stresses in the specification for the proposed bridge across Sydney Harbour were 16,500 pounds per square inch (104 MPa) for road traffic and 11,500 psi (79 MPa) for rail traffic after impact loads were taken into account.

Example 1.

The view of Pyrmont Bridge, Sydney, in Section 5C shows the steel swing span unit between approach spans comprised of Allan type timber trusses. The swing span was imported from Belgium and the Bridge was completed in 1902. The span was subject to considerable remedial attention during the restoration process of the 1990s so that pedestrian, cycle and (for a while) monorail traffic could be carried. The swing span, which continues to operate regularly, was one of the first in the world to be powered by electricity.

Example 2.

The Commonwealth Bank Building on Pitt Street in the central business district of Sydney was completed in 1916 and is shown in Section 5D. It is recognised as being the first fully framed steel construction in Sydney. There are ten floors above ground, with the columns and floor grid encased in concrete. The spacing between the columns varies from 4.27 metres to 6.93 metres. The building has recently been refurbished: mainly for non-bank use.

Examples of steel sections used in different periods as well as information on wrought and cast iron may be found in: "Historical Structural Steelwork Handbook" published by the British Constructional Steelwork Association in 1984 (624.1821 94).

Steel has a much higher susceptibility to corrosion than cast iron, as already noted. This means that a more intensive and thorough inspection procedure, including greater frequency, is necessary when compared with these other metals. With older structures, there is a high probability that the removal of the corrosion before repainting will encounter paintwork from another era when the paint contained substantial quantities of lead compounds. This creates an occupational health hazard that requires special measures such as sealing off the work area and its atmosphere from the public and the use of clothing providing maximum protection for the workers.

In well-maintained steel structures the above process of regular inspection and maintenance is likely to already have existed virtually since the structure was first commissioned. A particularly rigorous assessment is however needed when major decisions are to be made for extended use or re-use for a different function. This is especially true in the latter case where, under New South Wales legislation, a conservation management plan is mandatory.

A basic checklist for this purpose would be similar to that shown in Section 5E for a steel road bridge. The assessment then uses four grades of capability (or deterioration) as in the scale used by the Roads & Traffic Authority NSW which is shown. The ratings scale of the National Bridge Inventory of the USA in Section 5F is not only useful for steel but could be adapted for wider use with heritage structures. The faults listed in this scale give good hints as to what to look for.

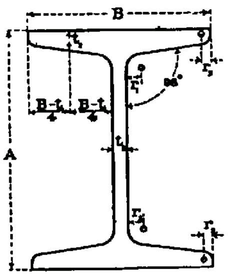
Another factor that could be likened to an enforced change of use is the increase in vehicle loadings that has occurred and the projected values that are likely. This is shown in the time chart in Section 5F.

The CIRIA C664 report: “Iron and steel bridges: condition appraisal and remedial treatment” can be downloaded via:

www.ciria.org/Resources/Free_publications/iron_and_steel_bridges_intro.aspx

AUSTRALIAN STANDARD SECTIONS.

BEAMS.



a = Sectional Area in square inches

3·4 a = Weight in lb. per foot (approximately).

1	2	3	4	5	6	7	8
Reference Number.	Size. A × B	Approx. Weight per foot.	Standard. Thickness. Web. t_1	Flange. t_2	Radii. Root. r_1	Toe. r_2	Sectional Area. a
	Inches.	lb.	Inches.		Inches.		Inches.^{2}
ASB 1	3 × 1½	4	·16	·249	·25	·12	1·177
ASB 2	4 × 3	10	·24	·347	·37	·18	2·940
ASB 3	4½ × 2	7	·19	·322	·29	·14	2·060
ASB 4	6 × 3	12	·23	·377	·37	·18	3·533
ASB 5	6 × 5	25	·33	·561	·53	·26	7·351
ASB 6	7 × 3½	15	·25	·398	·41	·20	4·416
ASB 7	8 × 4	18	·28	·398	·45	·22	5·296
ASB 8	8 × 6	35	·35	·648	·61	·30	10·296
ASB 9	9 × 4	21	·30	·457	·45	·22	6·177
ASB 10	10 × 4½	25	·30	·505	·49	·24	7·354
ASB 11	10 × 6	40	·36	·709	·61	·30	11·771
ASB 12	10 × 8	55	·40	·783	·77	·38	16·177
ASB 13	12 × 5	30	·33	·507	·53	·26	8·827
ASB 14	12 × 8	65	·43	·904	·77	·38	19·122
ASB 15	13 × 5	35	·35	·604	·53	·26	10·298
ASB 16	14 × 5½	40	·37	·627	·57	·28	11·765
ASB 17	15 × 6	45	·38	·655	·61	·30	13·236
ASB 18	16 × 6	50	·40	·726	·61	·30	14·705
ASB 19	16 × 8	75	·48	·938	·77	·38	22·063
ASB 20	18 × 6	55	·42	·757	·61	·30	16·182
ASB 21	20 × 6½	65	·45	·820	·65	·32	19·119
ASB 22	22 × 7	75	·50	·834	·69	·34	22·064
ASB 23	24 × 7½	100	·60	1·070	·70	·35	29·392

AUSTRALIAN STANDARD SECTIONS.

BEAMS.

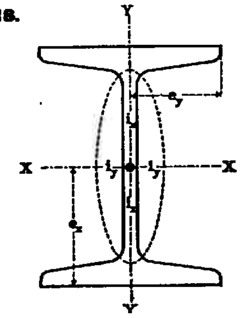
c_x c_y Distance of Centre of Gravity from X axis and Y axis.

$J = ai^2$ Moment of Inertia.

$i = \sqrt{\frac{J}{a}}$ Radius of Gyration.

e_x e_y Distance of outer fibres from X and Y axis.

$Z = \frac{J}{e}$ Modulus of Section.

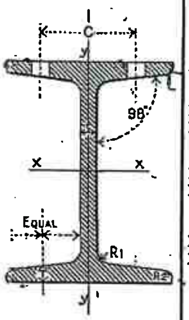


9	10	11	12	13	14	15	16	17
Centre of Gravity. C_x	C_y	Moments of Inertia J_x	J_y	Radii of Gyration. i_x	i_y	Moduli of Section. Z_x	Z_y	Reference Number.
Inches.		Inches.^{4}		Inches.		Inches.		
0	0	1·660	·125	1·188	·326	1·107	·167	ASB 1
0	0	7·786	1·326	1·627	·672	3·893	·884	ASB 2
0	0	6·652	·383	1·797	·431	2·957	·383	ASB 3
0	0	20·989	1·461	2·437	·643	6·996	·974	ASB 4
0	0	45·162	9·876	2·479	1·159	15·054	3·951	ASB 5
0	0	35·904	2·408	2·851	·738	10·258	1·376	ASB 6
0	0	55·629	3·506	3·241	·814	13·907	1·753	ASB 7
0	0	115·058	19·540	3·343	1·378	28·764	6·513	ASB 8
0	0	81·127	4·148	3·624	·820	18·028	2·074	ASB 9
0	0	122·338	6·486	4·079	·939	24·468	2·883	ASB 10
0	0	204·803	21·759	4·171	1·360	40·961	7·253	ASB 11
0	0	288·688	54·743	4·224	1·840	57·738	13·686	ASB 12
0	0	206·931	8·770	4·842	·997	34·488	3·508	ASB 13
0	0	487·769	65·184	5·051	1·846	81·295	16·296	ASB 14
0	0	283·507	10·815	5·247	1·025	43·616	4·326	ASB 15
0	0	377·059	14·788	5·661	1·121	53·868	5·377	ASB 16
0	0	491·912	19·871	6·096	1·225	65·588	6·624	ASB 17
0	0	618·092	22·468	6·483	1·236	77·261	7·489	ASB 18
0	0	973·909	68·303	6·644	1·759	121·739	17·076	ASB 19
0	0	841·759	23·635	7·212	1·209	93·529	7·878	ASB 20
0	0	1,226·172	32·559	8·008	1·305	122·617	10·018	ASB 21
0	0	1,676·796	41·065	8·718	1·364	152·436	11·733	ASB 22
0	0	2,654·769	66·874	9·504	1·508	221·230	17·832	ASB 23

DORMAN, LONG & CO. LIM

DIMENSIONS AND PROPERTIES

For safe distributed loads see pages 46 and 47.



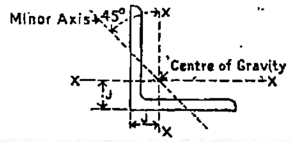
Reference Mark	Size Inches	Weight per Foot lbs.	Area Square Inches	Moments of Inertia About X-X	Moments of Inertia About Y-Y	Radii of Gyration Inches About X-X	Radii of Gyration Inches About Y-Y	Section Modulus About X-X
BSB 30	24×7½	100	29·4	2654	66·92	9·5	1·5	221·1
" 29	20×7½	89	26·17	1670	62·63	7·99	1·54	167·0
" 28	18×7	75	22·06	1149	47·04	7·21	1·46	127·6
" 27	16×6	62	18·23	725·7	27·08	6·31	1·21	90·71
" 26	15×6	59	17·35	628·9	28·22	6·02	1·27	83·85
" 25	15×5	42	12·35	428·	11·81	5·88	·978	57·06
" 24	14×6	57	16·76	532·9	27·96	5·63	1·29	76·12
" 23	14×6	46	13·53	440·5	21·6	5·7	1·26	62·92
" 22	12×6	54	15·88	375·5	28·3	4·86	1·33	62·58
" 21	12×6	44	12·94	315·3	22·27	4·93	1·31	52·55
DLB 20A	12×5	39	11·47	260·9	12·16	4·77	1·03	43·48
BSB 20	12×5	32	9·41	220·	9·753	4·83	1·01	36·66
" 19	10×8	70	20·6	344·9	71·67	4·09	1·86	68·98
" 18	10×6	42	12·35	211·5	22·95	4·13	1·36	42·3
DLB 17A	10×5	35	10·29	167·2	11·89	4·03	1·07	33·45
BSB 17	10×5	30	8·82	145·6	9·79	4·06	1·05	29·12
" 16	9×7	58	17·06	229·5	46·3	3·66	1·64	51·0
DLB 15A*	9¼×3¾	21·5	6·324	83·41	3·446	3·63	·738	18·03
BSB 15	9×4	21	6·176	81·1	4·2	3·62	·824	18·02
" 14	8×6	35	10·29	110·5	17·95	3·27	1·32	27·62
" 13	8×5	28	8·24	89·32	10·26	3·29	1·11	22·33
DLB 12A	8×4	25	7·353	75·06	5·502	3·19	·865	18·77
BSB 12	8×4	18	5·294	55·69	3·578	3·24	·822	13·92
" 11	7×4	16	4·706	39·21	3·414	2·88	·851	11·2
" 10	6×5	25	7·35	43·61	9·116	2·43	1·11	14·53
" 9	6×4½	20	5·88	34·62	5·415	2·42	·959	11·54
DLB 8A	6×3	16	4·706	26·16	1·957	2·36	·645	8·718
BSB 8	6×3	12	3·53	20·21	1·339	2·39	·616	6·786
DLB 7A*	5×5	24	7·059	29·30	9·751	2·04	1·18	11·72
BSB 7	5×4½	18	5·29	22·69	5·664	2·07	1·03	9·076
DLB 6A	5×4 7/16	19	5·588	22·34	4·756	2·00	·923	8·937
BSB 6	5×3	11	3·235	13·61	1·462	2·05	·672	5·444
DLB 5A	4¾×1¾	10	2·941	9·275	·413	1·78	·375	3·905
BSB 5	4¾×1¾	6·5	1·912	6·73	·263	1·87	·37	2·833
" 4	4×3	9·5	2·794	7·52	1·281	1·64	·677	3·76
DLB 3A	4×1¾	8	2·353	5·328	·324	1·50	·371	2·664
BSB 3	4×1¾	5	1·47	3·668	·186	1·58	·355	1·834
" 2*	3×3	8·5	2·5	3·787	1·262	1·23	·71	2·524
DLB 1A	3½×1½	6	1·765	3·086	·183	1·32	·322	1·763
BSB 1	3×1½	4	1·176	1·659	·124	1·18	·324	1·106

The properties of British Standard Sections in above table permission of the Engineering Standards Comm

The properties of British Standard Sections in above permission of the Engineering Standards

EQUAL ANGLES.

DIMENSIONS AND PROPERTIES.



Reference Mark	Size and Thickness	Area Square Inches	Weight per Foot Lbs.	Radii Root	Radii Toe	Dimension J	Moment of Inertia XX	Section Mod'lus XX	Least Radius of Gyrt'n
BSEA 16*	8 ×8 ×½	7·75	26·35	·600	·425	2·15	47·4	8·10	1·58
" 16*	" " ⅝	9·609	32·67	·600	·425	2·20	58·2	10·03	1·57
" 16*	" " ¾	11·437	38·89	·600	·425	2·25	68·5	11·81	1·56
" 14	6 ×6 ×7/16	5·062	17·21	·475	·325	1·64	17·3	3·97	1·18
" 14	" " ⅝	7·112	24·18	·475	·325	1·71	23·8	5·55	1·18
" 14	" " ¾	8·441	28·70	·475	·325	1·76	27·8	6·56	1·17
" 13	5 ×5 ×⅜	3·610	12·27	·425	·300	1·37	8·51	2·34	·98
" 13	" " ½	4·750	16·15	·425	·300	1·42	11·0	3·07	·98
" 13	" " ⅝	5·860	19·92	·425	·300	1·47	13·4	3·80	·98
" 12*	4½×4½×⅜	3·236	11·00	·400	·275	1·22	6·14	1·87	·88
" 12*	" " ½	4·252	14·46	·400	·275	1·29	7·92	2·47	·87
" 12*	" " ⅝	5·236	17·80	·400	·275	1·34	9·56	3·03	·87
" 11	4 ×4 ×⅜	2·859	9·72	·350	·250	1·12	4·26	1·48	·78
" 11	" " ½	3·749	12·75	·350	·250	1·17	5·46	1·93	·77
" 11	" " ⅝	4·609	15·67	·350	·250	1·22	6·56	2·36	·77
" 10	3½×3½×5/16	2·091	7·11	·325	·225	·975	2·39	·95	·68
" 10	" " ⅜	2·485	8·45	·325	·225	1·00	2·80	1·12	·68
" 10	" " ½	3·251	11·05	·325	·225	1·05	3·57	1·46	·68
" 10	" " ⅝	3·985	13·55	·325	·225	1·09	4·27	1·77	·68
" 9	3 ×3 ×¼	1·44	4·90	·300	·200	·827	1·21	·56	·59
" 9	" " ⅜	2·111	7·18	·300	·200	·877	1·72	·81	·58
" 9	" " ½	2·752	9·36	·300	·200	·924	2·19	1·05	·58
" 9	" " ⅝	3·362	11·43	·300	·200	·970	2·59	1·28	·58
" 7	2½×2½×¼	1·187	4·04	·275	·200	·703	·677	·38	·48
" 7	" " 5/16	1·464	4·98	·275	·200	·728	·822	·46	·48
" 7	" " ⅜	1·733	5·89	·275	·200	·752	·962	·55	·48
" 7	" " ½	2·249	7·65	·275	·200	·799	1·21	·71	·48
" 6	2¼×2¼×3/16	·809	2·75	·250	·175	·616	·378	·23	·44
" 6	" " ¼	1·063	3·61	·250	·175	·643	·489	·30	·44
" 6	" " 5/16	1·309	4·45	·250	·175	·668	·592	·37	·43
" 6	" " ⅜	1·547	5·26	·250	·175	·692	·685	·44	·43
" 5	2 ×2 ×3/16	·715	2·43	·250	·175	·554	·260	·18	·39
" 5	" " ¼	·938	3·19	·250	·175	·581	·336	·24	·39
" 5	" " 5/16	1·153	3·92	·250	·175	·605	·401	·29	·38
" 5	" " ⅜	1·36	4·62	·250	·175	·629	·467	·34	·38
" 4	1¾×1¾×3/16	·622	2·11	·225	·150	·495	·172	·14	·34
" 4	" " ¼	·814	2·77	·225	·150	·520	·220	·18	·34
" 4	" " 5/16	·997	3·39	·225	·150	·544	·264	·22	·34
" 3	1½×1½×3/16	·526	1·79	·200	·150	·434	·105	·10	·29
" 3	" " ¼	·686	2·33	·200	·150	·458	·134	·13	·29
" 3	" " 5/16	·839	2·85	·200	·150	·482	·153	·16	·29
" 2	1¼×1¼×3/16	·433	1·47	·200	·150	·371	·058	·07	·24
" 2	" " ¼	·561	1·91	·200	·150	·396	·073	·09	·23

PYRMONT BRIDGE, SYDNEY: STEEL SWING SPAN/TIMBER TRUSS

APPROACH SPANS, 1902

Photo:IGB

COMMONWEALTH BANK, SYDNEY: STEEL FRAME, 1916

Photo: IGB

STEEL ELEMENTS

For each of the condition states, report the estimated area in square metres.

Condition state descriptions

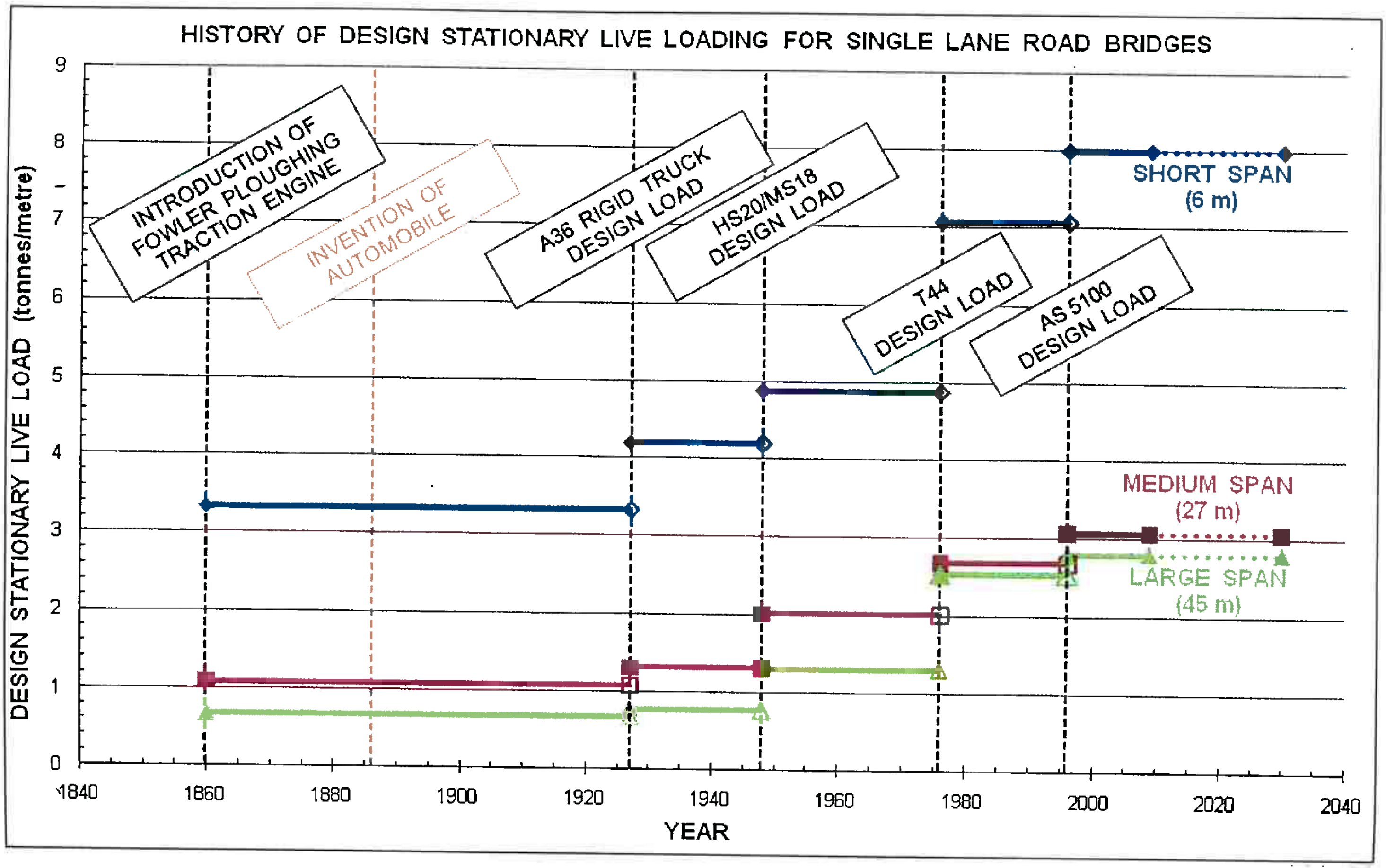
Condition State	Description
1	There is no evidence of section loss or damage or cracking.
2	Surface rust or minor pitting has formed or is forming. There is no measurable loss of section. There may be minor deformations that do not affect the integrity of the element. There are no cracks in the steel or welds. All bolts and rivets are in sound condition.
3	Heavy pitting may be present. Some measurable section loss is present locally, but not critical to structural integrity and/or serviceability of the element. There may be some loose or missing bolts or rivets. Defects have been assessed as not sufficient to impact on the ultimate strength and/or serviceability of the element.
4	Section loss is sufficient to warrant analysis to ascertain the impact on the ultimate strength and/or serviceability of either the element or the bridge. There may be cracks and/or deformations in the steel or welds. There may be numerous failed or missing bolts or rivets. Defects may impact on the ultimate strength and/or serviceability of the element.

Key Areas to inspect for any cracking, section loss and other deterioration signs:

1. Edges of members
2. Connections
3. Splice Plates
4. End plates of girders
5. Bottom chords of trusses

Rating Guidance Notes:

Defects are defined as notches, gauges or discontinuities.
Deformations are defined as buckled plate, bent members or sections
Section loss is defined as loss of original metal.



Live Loading for Australian Roads

C: Blackwell/Alcorn/Elias

6. CONCRETE

Early European settlers in Australia had been able to make lime from marine shells for use in mortar for buildings but the production of cement in Australia did not start until the second half of the nineteenth century. The first manufacturing facilities in Australia were in South Australia and Victoria. New South Wales cement production started towards the end of the nineteenth century with plants located in the limestone areas just west of the Blue Mountains at Kandos and Cullen Bullen. Closer to Sydney, the twentieth century enterprise of Mr E. G. Stone was located on the northern side of Narrabeen Lakes.

Mass concrete had its early use in gravity dams in Victoria in the 1860s. It was also used in the foundations of buildings and also in floors on grade from this time onwards. Black Bob's Creek Bridge (1896) near Berrima, NSW, is an example of an unreinforced concrete arch span.

Reinforced concrete design, as it is now understood, had two main pioneers in Australia: John Monash in Victoria and W. J. Baltzer, based in New South Wales. The latter had been made redundant by the Department of Public Works of NSW in the great economic depression in Australia in the 1890s. He returned to Europe for two years and used his time there in researching the latest developments in the emerging technology of reinforced concrete, which were occurring mainly in Germany and France. He came back to Australia to work as a consultant in this field, his main association being with the contractors Carter, Gummow in Sydney.

In this period, the name "Monier" was used for reinforced concrete in deference to the early nineteenth century originator of the idea of strengthening mortar with wrought iron rods.

Many attempts were made by individuals and companies to obtain patent rights of the system by proposing a wide range of variations of reinforcement designs but eventually they were ruled as being trivial changes. An excellent summary of local developments in this period is contained in the paper by D. J. Fraser: "Early developments in reinforced concrete in New South Wales (1895-1915)" in the Multidisciplinary Transactions of the Institution of Engineers Australia, Vol.GE9, No.2, October 1985 pp 82-91. A contemporary view of the "Monier System" can be found in a paper by Baltzer in the 1897 Minutes of Proceedings of the Engineering Association of New South Wales.

The London building regulations in the 1920s were requiring a 28-day concrete compressive strength of 1,800 pounds per square inch (12.4 MPa). In 1921 Professor W. H. Warren of the University of Sydney was reporting an average 90-day strength of 2,250 pounds per square inch (15.5 MPa) which he deemed to be equivalent to a 28-day strength of 1,810 pounds per square inch.

Example 1.

The construction of a major sewer to serve the inner-western suburbs of Sydney required the bridging of the valleys of Johnston's Creek and White's Creek, located on each side of the

Annandale ridge. After comparison with the designs for brick arch structures, the tender of Carter, Gummow and their design in reinforced concrete by Baltzer was accepted. The Annandale Sewer Aqueducts were completed in 1896 and were the first significant reinforced concrete structures in Australia. After refurbishment in 1997 (Section 6A), they continue in service.

Example 2.

The survival of a heritage structure is often linked to the possibility of an alternative use being found. Crago Mill is located just west of Newtown Station in inner-western Sydney. This large flour-milling enterprise dates from the late nineteenth century and the older part, which is of brick construction, was converted to offices. The more interesting area of the project however, concerns the c1936 tall, tubular, reinforced concrete silos that were built to hold grain. A thorough assessment of the condition of the concrete opened the way towards cutting holes in the silo walls to provide the windows of a fourteen-storey prestige apartment tower structure.

As with many projects, it is sometimes necessary to have additions to the original structure in order to tip the scales in the direction of economic viability. The vertical (penthouse) and horizontal additions are clearly noticeable in Section 6B but the old silo structure from the 1930s is also still easily seen.

The era of modern reinforced concrete can be said to have been with us for about one-and-a-quarter centuries and mass concrete for not much longer than that. There have been, in this time span, periods of much learning, many of which were triggered by error and disillusionment.

Overall, the need for good quality control was not appreciated in earlier times. One specific example was that, perhaps surprisingly to us, the realisation of the usefulness of testing concrete at the time of pouring, such as by test cylinders or cubes, did not come early. Thorough tests were carried out to determine the quality of the cement to be used and the grading and the quality of the aggregates but the possibility of testing a stage or two later in the production process – closer to the proof of the pudding – is absent from much of the literature. Another generator of future problems was the failure to provide adequate cover for the reinforcement that would endure over time. (See Reference 7)

There was a strong reaction to the resulting problems in that the cement and concrete industry carried out an information campaign directed at all employment sectors involved in construction. The literature and training that came out of this can certainly be said to have been beneficial.

This means that older concrete structures do need to be approached with some caution as regards future possibilities. Fortunately, recent times have seen many advances in the development of equipment for monitoring the health of concrete and similar structures, particularly in the area of non-destructive testing.

Without descending into paranoia, the useful table in Section 6C shows areas in which vigilance is necessary in assessing concrete.

Example 3.

One of the defects of materials encountered in the assessment of concrete structures – not only those classed as heritage – is the incidence of what is widely known as "concrete cancer". This occurs when corrosive ions such as chloride are able to reach steel reinforcement and cause rusting. As the rust is capable of increasing the effective diameter of the steel several times, the resulting expansion force is sufficient to break the concrete and spalling cracks then appear in the outside surface. Brown rust stains are usually detected some time later and eventually the failed concrete piece falls off. The building shown in Section 6D illustrates the progress in a structure fifty-three years old. Unfortunately the phenomenon is frequently also found in much younger buildings: ones that are well short of any useful economic lifespan of the structures.

https://failures.wikispaces.com/+Overview+of+Types+and+Causes

Corrosion meters can be used in the inspection process and it may be considered an advantage in that the fault is so widespread that it has generated more sophisticated materials for repair and many organisations that offer skills in remedial work.

Example 4.

The building shown in Section 6E was completed as a factory in 1931. The deterioration of the concrete is very apparent, as is the high exposure of the distribution steel. It is, however, difficult to categorise the distress as traditional concrete cancer. There is a relatively small amount of corrosion visible relative to the amount of steel and the concrete that is missing tends to cover areas rather than being associated with points or lines. It does appear that the overall cause could be a lack of cover that was originally provided. It is noticeable that there is also a layer of rendering above the basic concrete surface, though whether this was part of the original construction or an afterthought to correct the situation is not clear. As hinted earlier, the period of construction would be within the steeper learning curve for modern construction when quality control and even design were developing.

Example 5.

The beachside block of apartments shown in Section 6F was built fifty years before the photograph and gives an example of the extent to which it is sometimes necessary to go to effect repair. This particular stretch of coastline is subject to beating by strong waves from the Pacific Ocean and has undergone much erosion in recent times. Not only are the columns subject to direct spray but there is also the continuing presence of a salt-laden atmosphere. There is also evidence of earlier patching.

An overview of concrete development and preservation may be found in:

https://www.nps.gov/tps/how-to-preserve/briefs/15-concrete.htm

ANNANDALE SEWER AQUEDUCTS: REINFORCED CONCRETE ARCHES, 1896

Photo: IGB

CRAGO MILL, NEWTOWN, SYDNEY: APARTMENTS IN FORMER SILOS

Photo: IGB

How and why concrete deteriorates

It is imperative to establish the cause of the concrete degradation or steel reinforcement corrosion before repairs are carried out. Poor understanding of the cause of the problem can result in inappropriate repairs.

Concrete decay

Concrete is a relatively durable and robust building material, but it can be severely weakened by poor manufacture or a very aggressive environment. Concrete degradation can be a cause for concern on its own, or in reinforced structures it may lead to decreased protection to the steel. This in turn encourages corrosion of the steel, often followed by cracking and spalling of the concrete.

Deterioration of concrete is due to either:
- chemical degradation of the cementitious matrix;
- corrosion of the reinforcement steel;
- physical damage (impact, abrasive and fire damage).

The most important causes of concrete deterioration are described below.

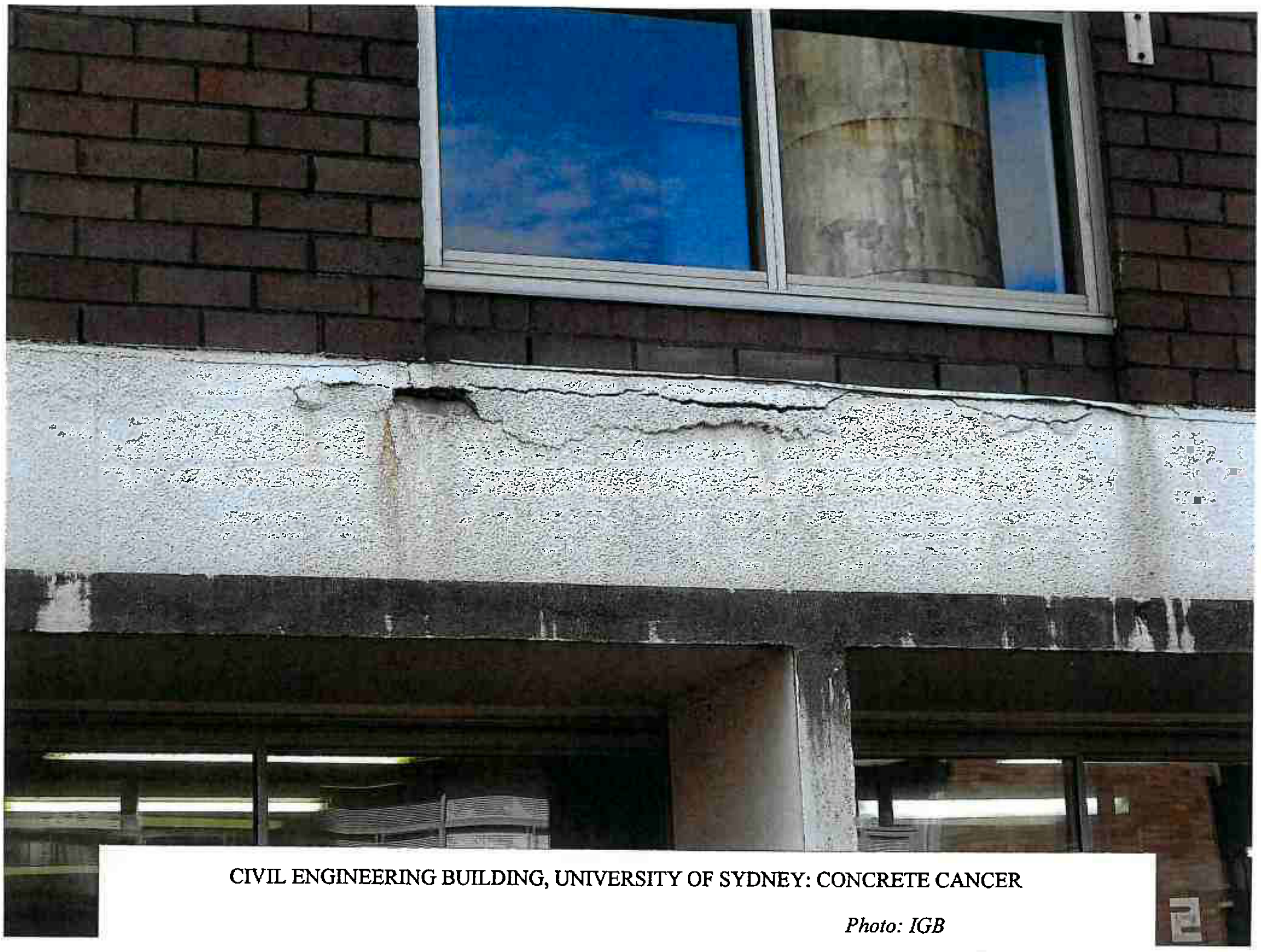
Causes of deterioration in reinforced concrete

Lack of maintenance and poor repair

When concrete first began to be used as a major structural building material, it was promoted as a material that needed little, or no maintenance. However lack of maintenance is a major contributor to reinforced-concrete deterioration.

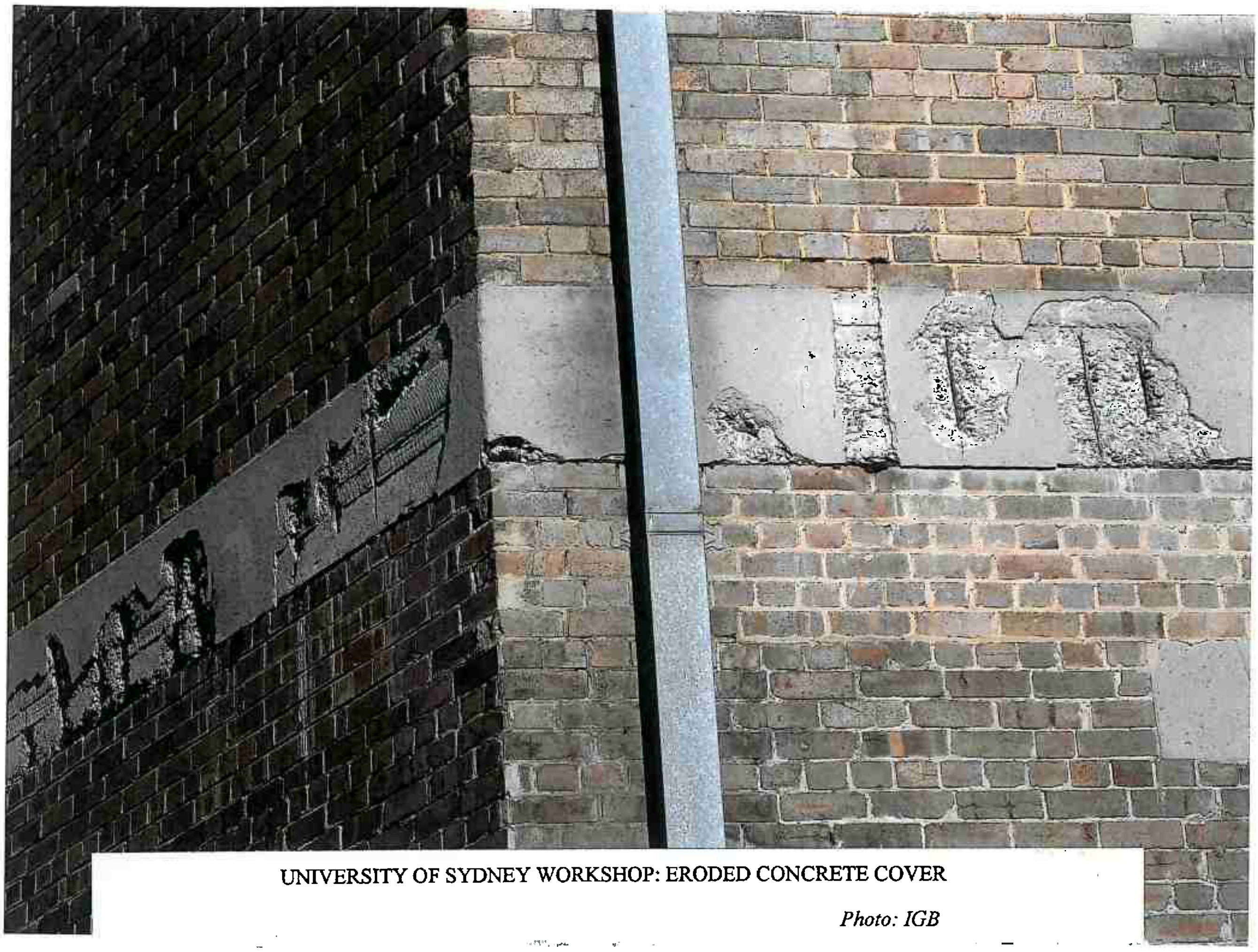
Sources of deterioration	Materials	Design and workmanship	Environmental	Physical damage
Potential causes of deterioration	Cement type/quality Mix design	Poor detailing	Presence of CO_2 and acid gases	Inadequate design
	Poor aggregate selection / reactivity	Insufficient cover to reinforcement	Freeze thaw	Impact
	Incorrect water:cement ratio	Poor drainage	Salt and chemical attack (de-icing salts, ground water)	Vibration
	Mechanical strength of aggregate	Inadequate design for creep	Biological growth	Settlement
	Additives or contaminants	Poor mixing	Weathering	Seismic
		Poor vibration and compaction	Thermal movement	Change of use increased floor loadings
		Bleeding and segregation	Fire damage	Wind
		Poor construction joints	Inadequate maintenance	
		Problematic finishes		
		Poor repairs		
		Inadequate maintenance		

The principal sources and causes of concrete deterioration.
Table by Susan Macdonald



CIVIL ENGINEERING BUILDING, UNIVERSITY OF SYDNEY: CONCRETE CANCER

Photo: IGB



UNIVERSITY OF SYDNEY WORKSHOP: ERODED CONCRETE COVER

Photo: IGB

COLLAROY BEACH APARTMENTS, SYDNEY: REPAIR OF CONCRETE

Photo:IGB

7. TIMBER

The earliest European settlement in Australia had an immediate need of local timber for the construction of habitation, especially for its use in roof spans. After early disappointments, it was found that Sydney blue gum *Eucalyptus saligna*, sometimes referred to as “flooded gum”, provided strength and durability properties above the average. Visitors to the 1819 Hyde Park Barracks in Sydney can easily see the king post roof trusses with a span of over thirteen metres.

But a greater prize was to be found as the settlement moved further from the coast and hardwoods were discovered that had strengths that were the rivals of any timbers worldwide. Chief amongst these was the grey ironbark *Eucalyptus paniculata*, closely followed by grey box *Eucalyptus boisistoana* and spotted gum *Eucalyptus maculata*. Tallowwood *Eucalyptus microcorys* not only had good strength properties but also had a surface hardness that made it attractive for flooring. Likewise, the durability of turpentine *Syncarpia laurifolia* was found to make it most suitable for marine structures.

The properties of all the above species are given in current timber design codes for assessment of existing structures but it is useful to correlate original design loads with the design timber strengths that were employed. Professor W. H. Warren of the University of Sydney took delivery of Australia’s first materials testing machine from Messrs Greenwood and Batley in 1885. As no data of the highest quality had yet been produced for Australian timbers, at the beginning of 1886 he started a programme of testing which his experience in the Department of Public Works of New South Wales indicated was badly needed to enable designers to put reliable numbers into their structural calculations.

Assisting with these tests was John A. McDonald of the Department of Public Works who promptly used the data in devising the McDonald type of timber truss for bridges, many of which were built as early as 1886. The first full, public airing of the results was in a government report published in 1887, the principal table from which is shown in Section 7A. (It will be necessary to multiply the pounds per square inch units by 0.0069 in order to produce megapascals.) This is a very important page because it could now be said that engineers had no excuse for using guesswork and simply their experience when designing timber structures. The numbers used in the table, together with modifications from further testing in 1893 and 1911, were the basis of good design for significant structures in Australia until the middle of the twentieth century.

As already hinted, grey ironbark was the timber of choice for most projects. In the third-last column of the table, its modulus of rupture for the extreme fibre stress in bending tests converts to 123 MPa. In the 1911 tests, this has been revised to 154 MPa for fully seasoned timber. It has been recently possible to test grey ironbark samples supplied by Roads & Maritime Services NSW that have been taken out of service after several decades. These have modulus of rupture values ranging from 100 MPa to 183 MPa. Other attractions of grey ironbark are its resistance to fire and to insect attack. General impressions are that, once the outermost weathered skin has been removed from the timber, the interior is extremely sound.

The middle section of the Warren table of results deals with compression tests on columns of four different value of slenderness. It will be noted that the grey ironbark failure stresses range from 56 MPa up to 70 MPa for a very short column. These values were of particular interest because, as indicated in Section 2A, timber column construction had been in use at least as far back as 1850. Typically, square timber columns would be used with a timber tee cap supporting the beams for the floor above. If it was being used on the ground floor, the column could be socketed at its base into a block of hard stone such as trachyte. The timber cap was in later years replaced by a wrought iron unit.

Example 1.

The building shown in Section 7B started life as a box factory in the year 1900. The columns support two floors above and are of a nominal eleven inches (280 mm) square cross-section. There are many larger buildings in existence that have columns with a cross-section of fourteen inches square. As will be seen, holes have been left in the ceiling so that the metal pile caps and floor structure are visible.

One of the last buildings to use this type of construction is the Schute, Bell, Badgery & Lumby woolstore at 100 Harris Street, Pyrmont, Sydney, the main stage of which was completed by Stuart Brothers in 1911. It has now been converted into offices. The Argyle Bond Stores in Argyle Street represents an earlier period and the interior is easily accessible to the public.

The existence of the hardwood resource unsurprisingly had an effect on the design of bridges. This was further aided by the mechanisation of the sawing process. Up to the middle of the nineteenth century, bridges had mainly been of the timber beam variety, with timber frame piers. The knowledge of bridges of the truss type, bearing names such as Howe, Pratt and Warren from overseas, encouraged local designers to exploit this field. Public Works engineer W. A. C. Bennett produced an arrangement of truss members ("Old PWD") that echoed European practice and this is shown in the first illustration in Section 7C.

As mentioned earlier, McDonald's timber trusses appeared in 1886, with the design advantages of accurate timber strength values. The design process was taken further by Percy Allan who adapted the Howe type from the USA to use Australian hardwood for the compression members and for the bottom (tension) chord. The Allan trusses were made in three standard span sizes of 21.3 metres, 27.4 metres and 33.6 metres although only three bridges using the last of these were built such as the Morpeth Bridge, New South Wales, shown in Section 7E. Details of an Allan truss of 27.4 metres are shown in Section 7D. It will be noted that the vertical tension members are made of wrought iron which was produced locally and the difficulties of the joints are overcome by using a number of different cast iron patterns that are shown in the lower right area of the drawing.

The cause of timber truss bridges was given an unlooked-for promotion when the great economic depression of the 1890s hit Australia. Steel in particular, which had to be entirely imported, became further out of reach of impoverished constructing authorities, both public and private. A three-span bridge at Wagga Wagga had been designed as trusses using local wrought iron flats and imported steel angles. Even this cheese-paring approach failed to bring the cost down to below that of an Allan type using 33.6 metre spans and this was the one that was built. This year of 1893 thus marked the start of the Allan truss period in bridge construction.

E. M. de Burgh used the Pratt truss format (Section 7F) in a similar way and the easing of the depression meant that some steel could be used in the bottom chords – as did H. H. Dare in reviewing the Allan/Howe format.

Many examples of the above types of truss (Section 7G) have been preserved in use by Roads & Maritime Services NSW and by other bodies. Some have been upgraded to accommodate higher wheel loads. The twelve approach spans of the 1902 Pyrmont Bridge, Sydney, which can be seen to the right of the swing span in Section 5C are of the Allan type (6 trusses per span) with the bridge deck on top. The loading is now only that of pedestrians and bicycles.

An overview of procedures for inspection, maintenance and repair of timber bridges can be found in the first part of the Timber Bridge Manual of Roads & Maritime Services NSW:

www.rms.nsw.gov.au/documents/projects/key-build-programs/maintenance/tbm-1.pdf

Some timber truss designs incorporate the facility for repair and replacement of a single timber member with minimal disturbance of the structure. Occasionally complete reconstruction of a truss has taken place. Because of the scarcity of grey ironbark that has developed, blackbutt, *Eucalyptus pilularis,* has been used. Although this is of slightly lower strength than grey ironbark, total redesign is necessary in any case because of predicted future loadings.

Information on the repair of timber heritage structures can be found on:

www.environment.nsw.gov.au/resources/heritagebranch/heritage/maintenance52timber.pdf

Principles to be followed in work on timber heritage structures are contained in:

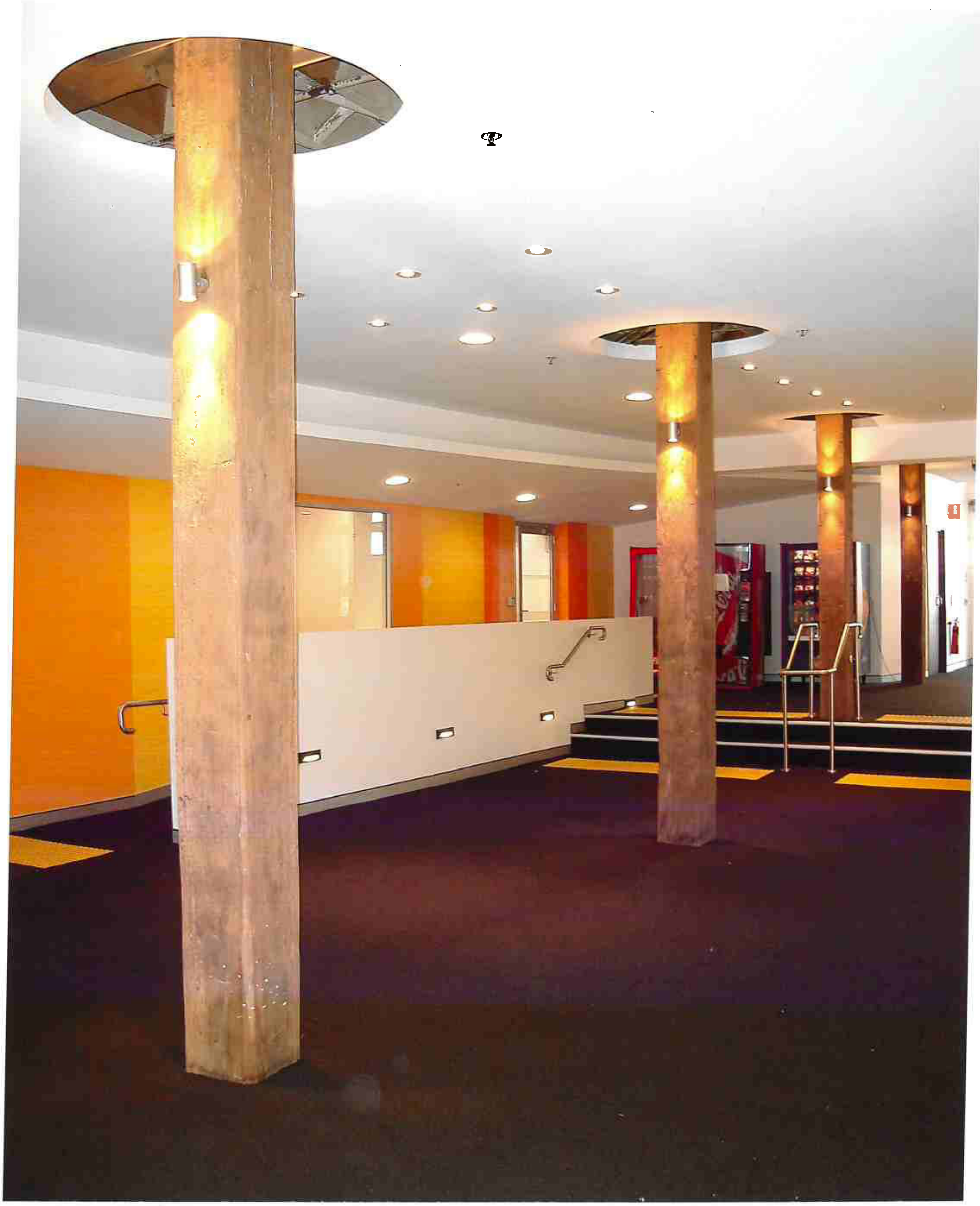
www.icomos.org/charters/wood_e.pdf

and reference should be made to pdf Practice Note No.6 of Engineering Heritage Australia: "Assessment and Conservation of a Timber Building".

Local Name.	Number and Letter.	Weight per cubic foot in lb.	Tension Tests.		Compression Tests.								Bending Tests.		Shearing Tests.
					Ratio of length of Column to smallest dimensions.										
					24 to 1		16 to 1		8 to 1		4 to 1				
			Breaking stress in lb. per square inch.	Modulus of elasticity in lb. per square in.	Breaking stress in lb. per square in.	Modulus of elasticity in lb. per square in.	Breaking stress in lb. per square in.	Modulus of elasticity in lb. per square in.	Breaking stress in lb. per square in.	Modulus of elasticity in lb. per square in.	Breaking stress in lb. per square in.	Modulus of elasticity in lb. per square in.	Modulus of rupture in lb. per square in.	Modulus of elasticity in lb. per square in.	Breaking stress in lb. per square in. along the grain.
Tallow-wood	F 3	77·06	16,165	2,274,790	6,943	2,222,298	7,721	2,163,360	6,373	1,618,803	7,585	1,663,201	15,257	2,287,532	1,802
Spotted gum	B 3	62·19	14,413	4,383,483	5,499	2,793,579	6,456	2,927,980	6,561	2,028,058	6,753	1,820,432	13,296	2,056,101	1,583
Blackbutt	B 4 / F 1	66·09	21,708	3,105,979	6,572	2,343,485	7,756	2,649,063	7,526	1,775,249	7,522	1,784,608	13,728	2,162,764	1,757
Swamp mahogany	B 6	75·08	16,520	....	5,263	2,524,987	6,113	2,559,380	6,569	1,796,229	6,846	2,494,505	12,124	2,098,701	1,166
Grey ironbark ...	B 1	73·85	25,080	5,526,400	8,112	3,074,679	9,482	3,354,236	9,112	3,500,000	10,165	....	17,866	2,484,799	2,187
Red ironbark......	B 2	76·52	19,009	....	7,701	2,770,985	8,760	3,254,172	9,403	1,770,556	9,281	1,879,734	16,275	2,341,802	2,012
White ironbark...	D 1	73·55	9,861	....	6,923	2,459,460	9,103	2,747,521	8,225	1,938,865	8,680	1,612,544	16,932	2,794,020	1,974
Woolybutt.........	B 5	63·89	19,968	4,495,266	5,542	2,605,892	6,121	2,303,768	7,074	1,935,845	6,981	1,314,657	12,708	2,140,443	1,729
Red gum	3 M	62·19	8,884	1,292,691	8,870	987,364	5,655	1,498,591	4,651	1,381,447	5,016	581,601	6,930	761,769	2,122
Grey gum	F 4	57·33	20,821	5,010,372	6,492	2,308,678	7,006	2,085,821	7,452	1,753,612	7,248	1,780,028	13,092	2,146,733	1,503
Flooded gum...	F 5	77·94	14,857	3,761,988	7,494	2,483,221	8,889	2,179,183	8,700	2,056,027	8,761	1,779,584	17,622	2,341,430	1,976
	A 3	69·34	16,952	2,507,263	5,566	1,854,580	5,786	1,837,792	5,905	1,341,473	5,889	1,333,385	12,023	1,943,398	1,559
Mountain ash ...	B 7	66·57	18,974	2,902,000	5,197	1,962,851	4,903	1,575,852	6,324	1,590,076	5,959	1,359,651	11,527	2,054,227	1,812
Blackwood	B 8	70·58	14,883	2,104,400	6,189	1,814,563	7,006	1,929,960	7,100	1,791,961	6,784	1,580,199	10,264	1,908,432	2,033
Grey box	D 2	73·62	22,415	2,547,100	7,210	2,606,847	8,031	2,594,558	8,525	2,344,415	8,021	1,753,462	16,209	2,766,435	1,791
Pine..................	D 3	54·31	15,001	3,263,000	4,489	1,922,626	...	....	4,530	1,258,870	4,199	1,181,619	8,824	2,408,267	1,222
Forest mahogany	D 4	72·23	14,115	2,315,400	5,106	2,025,073	6,329	2,095,276	5,386	1,124,000	7,967	1,879,257	13,769	3,040,883	1,607
Rose wood	D 5	74·29	13,578	2,268,750	5,271	1,965,086	5,593	1,773,963	5,371	1,202,261	6,011	1,144,837	10,594	1,937,474	1,722
White beech	D 6	63·03	9,934	2,794,750	6,276	2,072,272	6,858	1,736,143	7,241	1,458,828	8,253	1,229,278	15,607	2,421,119	2,066
Mahogony	F 2	75·06	19,753	3,741,876	7,699	2,451,424	7,902	2,138,100	9,061	2,059,898	7,514	1,588,160	14,500	2,258,372	2,109
Forest oak	A 0 / A 1	75·48	17,107 / 13,245	4,470,909 / 2,207,505	7,270	2,117,461	8,375	2,187,550	8,139	1,742,492	8,335	2,126,210	15,492	2,396,263	1,388
Turpentine.........	A 2	69·34	16,821	4,077,377	4,917	1,813,631	5,882	1,675,220	5,810	1,382,621	6,864	1,544,477	11,727	1,965,524	1,451
Stringy bark	A 4	71·33	19,399	2,761,812	5,685	2,128,870	5,565	1,810,923	6,575	1,790,161	5,985	1,234,109	13,931	2,353,044	1,942
Australian teak...	F 6	62·9	......	....	5,648	2,236,857	5,574	2,210,227	6,502	1,883,243	7,030	1,735,887	14,415	2,174,875	1,307

Sydney: Charles Potter, Government Printer.—1887.

Main disclosure of testing results obtained by Professor W. H. Warren in NSW government report of 1887: "The Strength and Elasticity of New South Wales Timbers" (Gov't Printer)



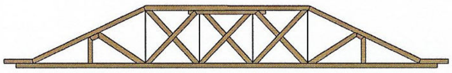
SERVICES BUILDING, UNIVERSITY OF SYDNEY: IRONBARK COLUMNS, 1900

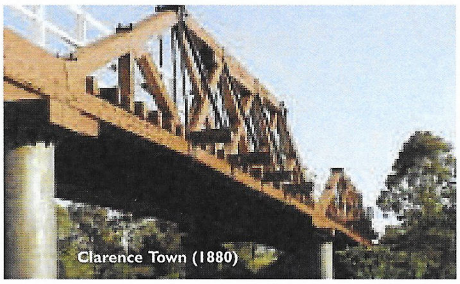
Photo: IGB

The evolution of timber truss bridge designs

There are five types of timber truss bridges in NSW:

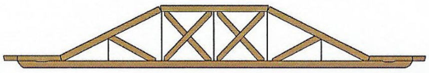
- **Old Public Works Department trusses**, built from 1860 to1886. These bridges were designed by British engineers working in NSW, and adopted British styles of construction.

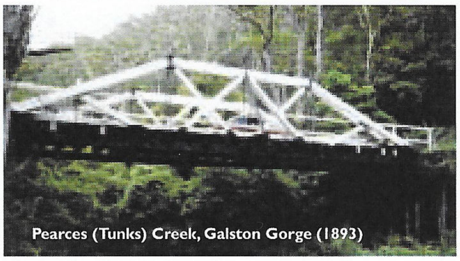




Clarence Town (1880)

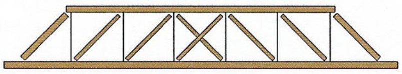
- **McDonald trusses**, built from 1886 to 1893, still using British styles of construction.





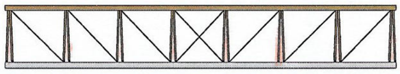
Pearces (Tunks) Creek, Galston Gorge (1893)

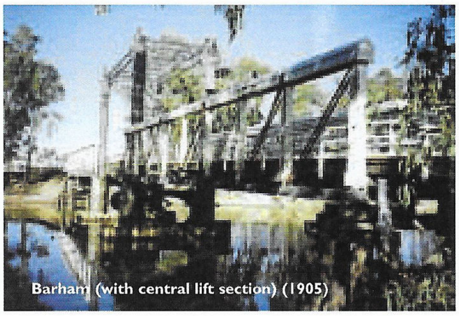
- **Allan trusses**, built from 1893 to 1929. This design was similar to the American Howe truss design, with cast iron connection pieces. The trusses were constructed in two halves, to facilitate maintenance.



Morpeth (1898)

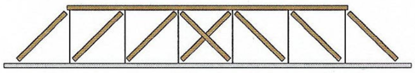
- **DeBurgh trusses**, built from 1899 to 1905. This was a pin-jointed design, similar to the American Pratt truss design. In some cases steel replaced timber for the bottom chord.

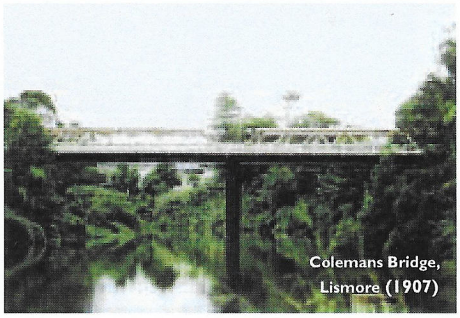




Barham (with central lift section) (1905)

- **Dare trusses**, built from 1905 to 1936. This design was very similar to the Allan truss, with the main difference being a steel bottom chord.





Colemans Bridge, Lismore (1907)

(The truss sketches above are from the Department of Main Roads' *Timber Truss Bridge Maintenance Manual*, 1987.)

From a heritage perspective these truss bridges are technically very significant.

Each type of truss represented an important technical advance over the last, in a process of evolution that culminated in NSW's having bridges of world class engineering design. It is therefore important for examples of each class of truss to be preserved.

As a group the truss bridges also have historical significance because of their contribution to the expansion of the NSW road network and hence the economic and social development of the State.

Many of the bridges have aesthetic significance, mainly through their landmark qualities and their functioning as "gateways" to a town or area, and social significance, being highly valued by their local communities.

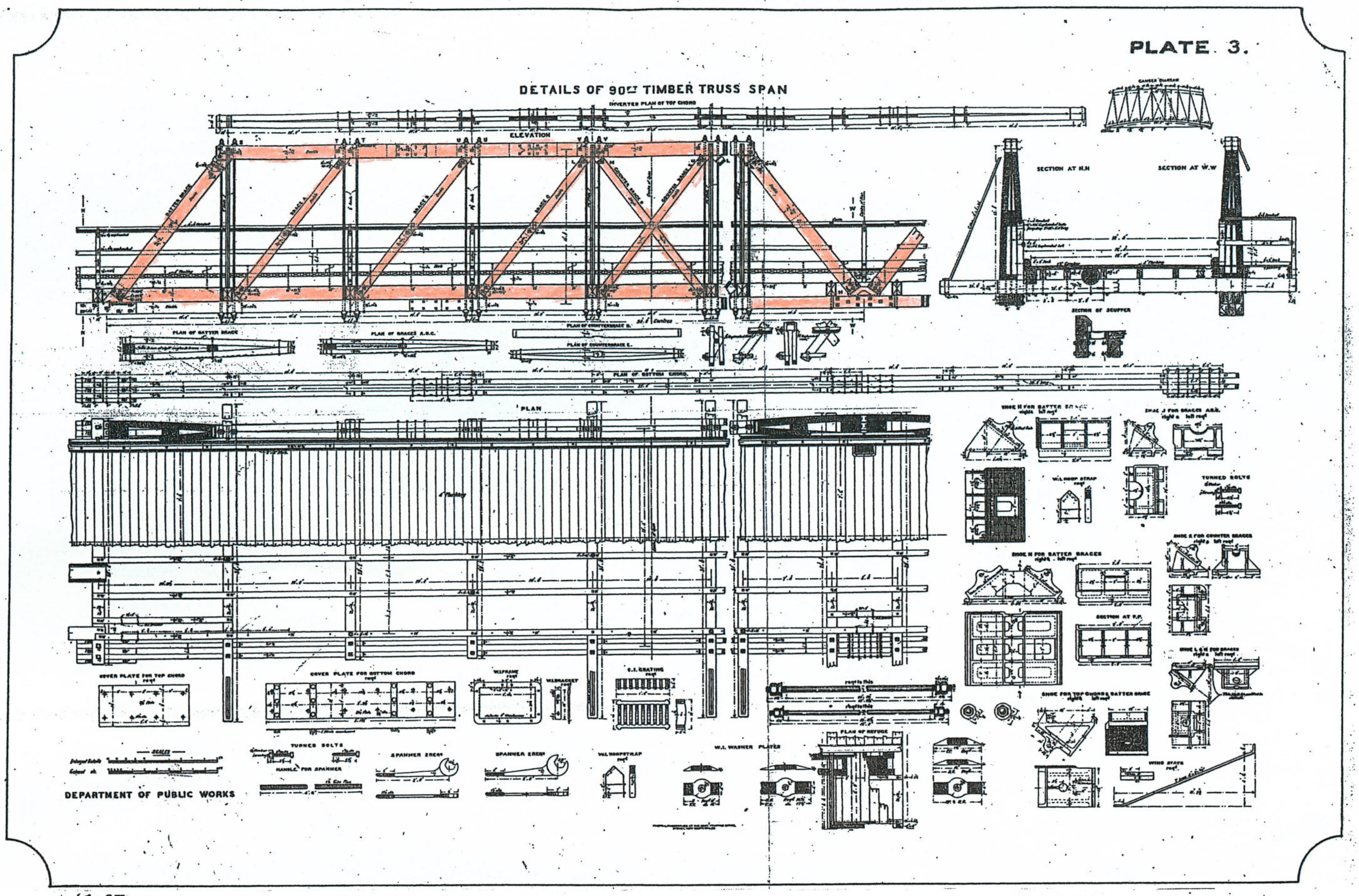
RTA

Truss type	Number built in NSW
Old Public Works Department	147
McDonald	91
Allan	105
DeBurgh	20
Dare	40
Total	422

Fraser, D.: "Timber Bridges of New South Wales", Multi-Disciplinary Transactions IEAust, Vol GE9 No.2 October 1985

"Timber Truss Bridges – Study of Relative Heritage Significance of All Timber Truss Bridges in NSW", Roads & Traffic Authority 1998

"Timber Truss Bridge Conservation Strategy", Revised 2012, RMS



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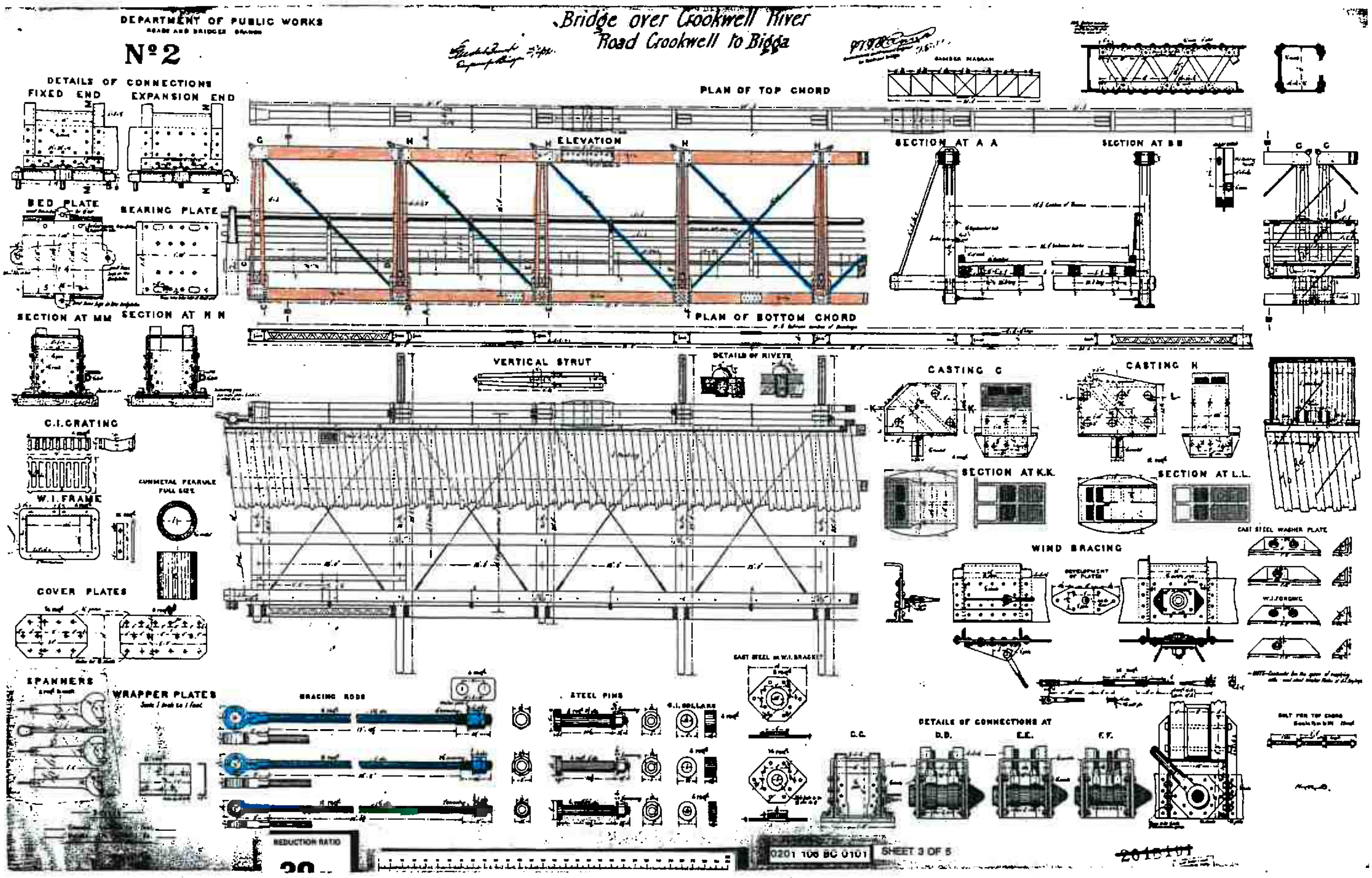
HALF SPAN OF ALLAN TYPE TIMBER TRUSS: 1893 – 1929

MORPETH BRIDGE, NEW SOUTH WALES: TIMBER ALLAN TRUSSES. 1898

Photo:IGB



HALF SPAN, DE BURGH TYPE TIMBER TRUSS: 1899-1905

TIMBER TRUSS BRIDGES PRESERVED BY ROADS AND MARITIME SERVICES OF NEW SOUTH WALES

Allan Design

A1 Hunter River at Morpeth, 1898

A2 Paterson River at Hinton, 1901*

A3 Paterson River at Woodville, Dunmore Bridge, 1899*

A4 Beryl Bridge, Wyaldra Creek, Gulgong, 1927

A5 Carrathool Bridge, Carrathool, 1922*

A6 Paytens Bridge, Forbes, 1926

A7 Rossi Bridge, Goulburn, 1899

A8 Swan Hill Bridge, Swan Hill, 1896*

A9 Victoria Bridge, Nr Picton Station, 1897

A10 Wallaby Rocks, Turon River, Sofala, 1897

A11 Wee Jasper, Tumut – Yass Road, 1896

De Burgh Design

B1 Barham Bridge over Murray River, 1905*

B2 Cobram Bridge over Murray River, 1902*

B3 Middle Falbrook over Glennies Creek, Singleton,1904

B4 St Albans Bridge, 1902

Dare Design

D1 Briner Bridge, Upper Coldstream River, 1908

D2 Colemans Bridge, Union Street, Lismore, 1908

D3 New Buildings Bridge, Wyndham, 1921

D4 Rawsonville Bridge, Macquarie River, Rawson, 1916

D5 Scabbing Flat Bridge, Wellington River, Geurie, 1911

D6 Warroo Bridge, Lachlan River, Condobolin-Warroo Road, 1909

Old Public Works Design

O1 Clarence Town, over Williams River, 1880

O2 Monkerai, over Karuah River, 1882

McDonald Design

M1 Tunks (Pearces) Creek, Galston Gorge, 1902

M2 Junction Bridge, over Tumut River, Tumut, 1895

M3 McKanes Falls Bridge, Coxs River, 7km S of Lithgow, 1893

* These bridges have a movable span.

8. STONE

The term: “masonry” unfortunately has a somewhat elastic meaning in that different users employ the word to include different materials. The description: “dimension stone” has some advantage here in that it commonly refers to original, monolithic, natural material that is cut to shape for structural purposes.

As a natural product, there is a wide range of this material of usable properties but three types are particularly noteworthy for local use.

It will readily be appreciated that the strengths of stone and brick structures are significantly dependent on the mortar in the joints – with, of course, the exception of some ancient, ingenious structures in which the fit between the joints was such that no mortar was used at all. Brick structures are more reliant on mortar and comment will be made in Section 9. The following reference does, however, specifically refer to the repair of joints in sandstone.

www.gsa.gov/portal/content/112998

Sandstone

The first European settlement in Australia quickly appreciated the constructional properties of the sandstone of the Sydney area. The Hawkesbury formation extends to about 75 km west of the coast. Apart from some areas covered by shale or clay, it is easily accessible in the metropolitan area. See Reference 16.

An expectation of its engineering properties with respect to foundation design is to be found in Section 8F.

A geological viewpoint is in:

www.environment.nsw.gov.au/resources/heritagebranch/heritage/franklin.pdf

The two main varieties of the Hawkesbury sandstone are the “Yellow block” and the “Quartz-rich”. It was the former that originally had much appeal because – perhaps rather ominously – it was easier to cut than other stones and, because of some iron content, it gradually weathered to an attractive golden brown. It was therefore much favoured by early architects but eventually it was discovered that it had certain properties on the debit side.

Its compressive strength of 40-50 MPa was a little below average when viewed in an international comparison and was even below that of sandstones from Queensland. However it was still within the usable range for structural purposes and it must be remembered that the modes of failure of masonry arches are mainly not related to the lack of strength of the construction material.

Much more serious was the poor durability of yellow block with regard to weathering. The impact of acid rain in the Sydney area for several decades would also not have helped, with a recorded pH value of 4.6 at one stage. There were for a time four coal-fired electricity power stations within four kilometres of the central business district, together with the use of coal by industry and domestically. Even before the industrial era, there were warnings that the sandstone was quite variable and had to be selected carefully. The first Macquarie Lighthouse, constructed in 1818, had to be replaced completely only sixty years later in spite of brave attempts to hold it together by iron bands.

The source of the level of rate of decay is that yellow block contains a clay matrix of up to 25% by weight. The government of New South Wales in particular has been impacted by this problem because a great many government buildings had been constructed of this material in the latter part of the nineteenth century and, after about a hundred years, damage and deterioration had set in. A programme of securing material for repair was put in place and the training of stonemasons – a much rarer breed in modern times – was introduced. The City of Sydney now reviews applications for the construction of tall buildings with an eye to examination of the excavated rock for deep foundations, in the event that it could be stockpiled for future repairs rather than being discarded as fill elsewhere.

The main process of deterioration of sandstone and other sedimentary materials is that the acid rain enters the exposed surface to a depth of a few millimetres. It concentrates its efforts, in effect, within this depth until the structural matrix is weakened to the extent that it is not able to support the weight of the surface material and a flake of this drops off, leaving a fresh surface to restart the process. An example of this, in the case of limestone is shown in Section 8E.

As indicated above, preference is for replacement of deteriorated stone units rather than repair of existing material but the following reference indicates what can be done if the latter process is adopted.

www.gsa.gov/portal/content/111954

Example 1.

The Department of Lands Building in Bridge Street, Sydney, was one of many buildings that were constructed by the government of New South Wales during a period of relative prosperity in the latter part of the nineteenth century, before the great depression of the 1890s. The exterior of the building (Section 8A) is composed of the yellow block type of Hawkesbury sandstone. The brown colour of the weathered stone is not as intense as with some other buildings of this age but there has been some cleaning of the stone in recent times.

The Department of Education Building, which can be seen beyond is of similar age and construction. The upper levels of the Commonwealth Bank Building shown in Section 5D are also of Hawkesbury sandstone.

Traces of repair of the Lands Building are detectable but have not been as extensive as with other buildings and the matching of the repair stone has been quite good. When using new stone for repair, some skill is required in selecting material that will eventually weather to the right shade of brown. Lighter patches are usually observed after repair but the expectation is that the colours will converge.

A good example of colour matching is to be found in the (now) top two floors of the Radisson Blu Hotel at the intersection of Pitt and O'Connell Streets, Sydney. (The viability of the conversion of the original building to a hotel required two further stories to be added.) The stone matching task is also illustrated in Section 8C which shows the completely new top section which had been necessary for the tower at the north-east corner of the yellow block sandstone of the Great Hall (1862) of the University of Sydney. The colour of the new section is virtually as the stone came out of the quarry and it is expected that it will eventually move towards a brown colour no too remote from that of the adjacent material. This photograph is also useful because it shows a range of weathered colours elsewhere on the structure as well as lighter repair patches. The adjacent main front of the University's Quadrangle area, including the clock tower, is constructed of the quartz-rich variety of sandstone. The need for repair has been somewhat less but there is still a substantial ongoing programme of maintenance.

Example 2.

The use of sandstone as a completely structural material is represented by a number of stone arch bridges such as the Lansdowne Bridge of 1836 in Section 8B which still carries the eastbound lanes of the Hume Highway over Prospect Creek in the Sydney suburb of Lansvale. The designer of this single span of 33.5 metres was David Lennox who worked with the famous engineer Thomas Telford in Britain. Similarities with Telford's arch bridges can be seen in this design. Lennox also was responsible for the first Princes Bridge in Melbourne (1851), Lennox Bridge, Glenbrook (1833) and the 27.4-metre Lennox Bridge, Parramatta (1839, Section 8D) although this last was later widened on the western side.

Trachyte

Geologically referred to as microsyenite, this hard, igneous material is to be found in accessible deposits in the Southern Highlands of New South Wales. It is of a grey-brown colour and can be polished to a highly smooth surface. It has been used extensively as a building material in the Sydney area, particularly as a facing material, and features prominently in the thorough listing of stones used in the buildings and kerbstones of Sydney's central business district that is included in "Field Geology of New South Wales" by D. Branagan and G. Packham : pp70-90 in 2000 edition (559.44 4 B). Its load-bearing function is exemplified in the many columns to be found in the local architecture where the required strength of the material is well below that which it can provide.

The Commonwealth Bank Building, shown in Section 5D, has trachyte facing for the tall, ground floor section with sandstone above.

The resistance of trachyte to weathering is very good and, as it is mainly used for facing, it is usually not necessary to mobilise its high strength, as described. See Reference 12.

Granite

A north-south line of igneous intrusions, between Canberra and the coast, intersects the coast at Moruya, 250 km south of Sydney. This is coarse-grained material of the granite/granodiorite type. The access by sea was the incentive for the establishment of quarries and stoneworks at Moruya.

The attractiveness of the grain when polished led to the extensive use of this material in the exteriors of buildings and it is mentioned frequently in the above reference. Although it is of high strength and is very suitable for structural purposes, its aesthetic qualities and cost have led it to be more noteworthy for building exterior work. As with trachyte, atmospheric erosion is not a significant problem.

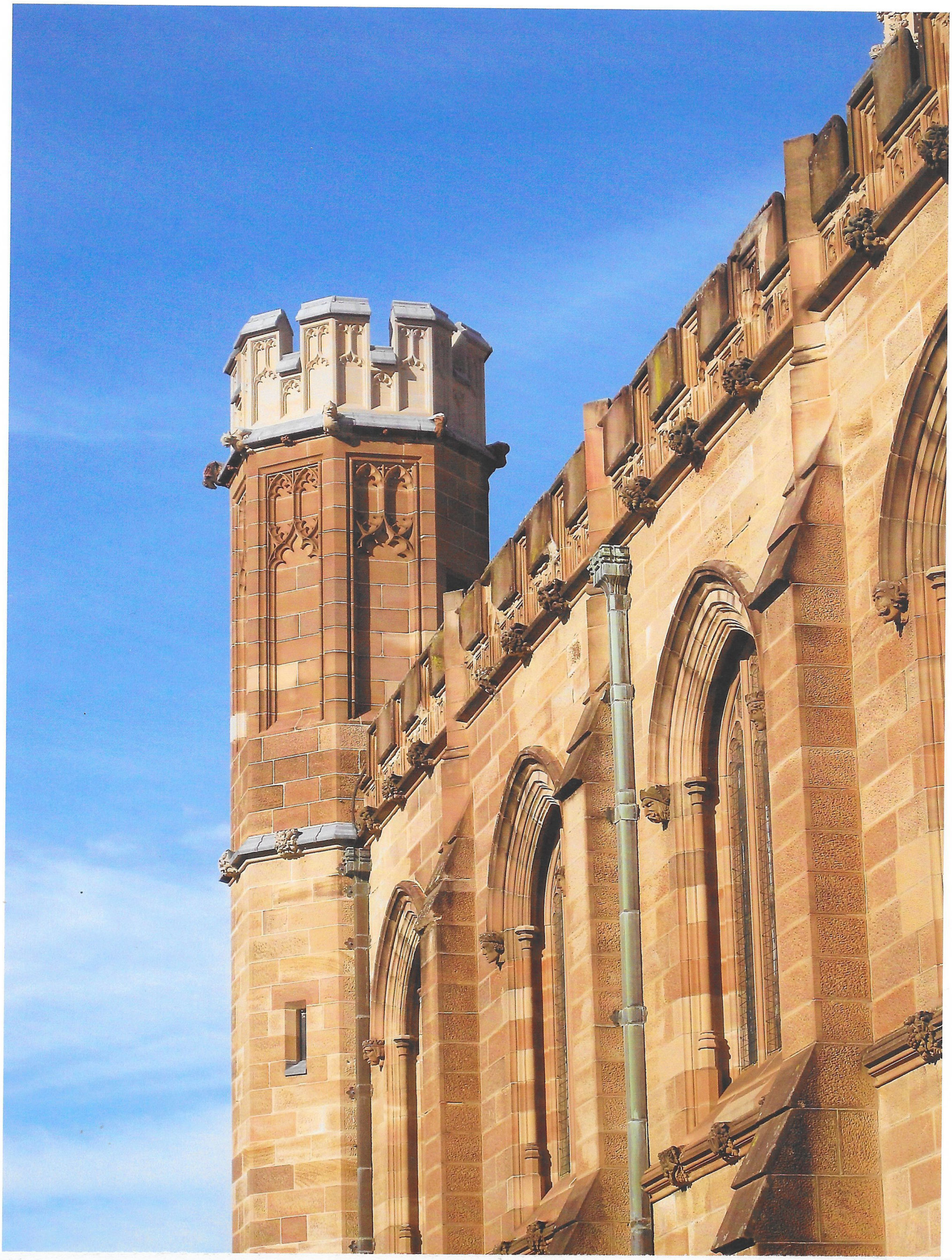
Possibly the best-known of the uses of Moruya granite is in the construction of the Sydney Harbour Bridge and especially of the pylons.

DEPARTMENT OF LANDS BUILDING, SYDNEY: SANDSTONE, 1876+

Photo: IGB

LANSDOWNE BRIDGE, LANSVALE, SYDNEY: SANDSTONE ARCH, 1836

Photo: IGB



GREAT HALL, UNIVERSITY OF SYDNEY: REPAIR OF TOP OF TOWER

Photo:IGB

LENNOX BRIDGE, PARRAMATTA: STONE ARCH, 1839

Photo: IGB

LAMINAR DETERIORATION OF MAGNESIAN LIMESTONE, YORK MINSTER, UK

Photo: IGB

DESIGN VALUES FOR FOUNDATIONS ON SANDSTONE

Class	General Description & Field Guide	Saturated Unconfined Compression Strength q_u MPa	Fracturing *	Allowable Defects *	End Bearing Pressure *	Shaft Adhesion *	$\frac{E_{field}}{E_{core}}$	Typical E_{field} MPa	Suggested Minimum Investigation or Proving Techniques
I	Strong sandstone, core sections of 50 mm dia. cannot be broken by hand and can be only slightly scratched with a steel knife.	> 24	Slightly fractured or unbroken	1.5%	Max. 12 MPa	0.05 f'_c	0.9	> 2000	Comprehensive site investigation sufficient to define seams & layers of rock - cored boreholes at not greater than 10 metre grid spacing. OR cored holes at not less than 50% of footings with jackhammer holes and spoon testing at the remainder.
II	Medium to strong sandstone - core sections can be broken by hand with difficulty and lightly scored with a steel knife.	12 - 24	Slightly fractured	3%	6 MPa OR 0.5 q_u Max. 10 MPa	600 kPa OR the lesser of 0.05 f'_c OR 0.05 q_u Max. 1200 kPa	0.7	900 -3000	
III	Medium strong sandstone - core sections can be broken easily by hand and readily scored with a steel knife.	7 - 12	Fractured	5%	3.5 MPa OR 0.5 q_u Max. 6.0 MPa	350 kPa OR 0.05 q_u Max. 600 kPa	0.5	350 -1200	Site investigation to include at least 4 cored boreholes with jackhammer holes and spoon testing. OR cores in at least $\frac{1}{3}$ of footings.
IV	Weak sandstone - core sections break easily and may be heavily scored or cut with a steel knife.	2 - 7	Fractured	10%	1 MPa OR 0.5 q_u Max. 3.5 MPa	100 kPa OR 0.05 q_u Max. 350 kPa	0.4	100 - 700	Engineer's site inspection with at least 2 cored boreholes.
V	Very weak sandstone - rock structure is evident but frequent zones of sugary sandstone - crumbled by hand.	Not normally measurable	Highly fractured or fragmented	-	0.8 - 1.0 MPa	75 - 150 kPa	-	50 - 200	

* See text for definitions and explanations.

9. BRICK

One of the first tasks undertaken by the first European settlement in Australia was to search for suitable clay for brick manufacture. This was quickly found in an area that has become the southern sector of Sydney's central business district. This was in production for about fifty years until urban growth and diminishing deposits meant that alternative sources had to be discovered.

These were conveniently found not too far away in what are now the inner western suburbs of Sydney and, across the Parramatta River, in the area of the Lower North Shore. These were in the extensive shale/clay deposits of the Wianamatta group of the Sydney Basin. There is some irony in that these areas, which provided such large quantities of building material, were also those where seasonal swelling and shrinkage of foundation soils were to cause damage to low-rise buildings.

Early labour in the brickyards was, of course, provided by convicts. However, variation in the quality of the product cannot be attributed solely to lack of skill or work ethic on the part of the operatives. One of the early problems was in attaining a sufficiently high temperature in the kilns in these early stages of the industry. It is clear that a range of quality of brick was produced and a careful inspection process would then select the better ones for higher level work.

This is illustrated in Section 1A where the brickwork of Hyde Park Barracks of 1817 still holds up well as one of the prestigious buildings of its time. This is to be contrasted with the brickwork of the adjacent guardhouse, in the right-hand photograph, which is in a somewhat sorry state, even though it would have been exposed to the same elements and atmospheric environment.

It was possible to carry out impact tests using a Schmidt hammer ("Silver", series L – low impact – with mushroom head) on brick construction of known dates in a heritage building.

-	1831	Q=34.6	c =18 MPa
-	1856	Q=35.2	c =18 MPa
-	1872	Q=40.6	c =26 MPa
-	1884	Q=42.7	c =30 MPa

The compressive strength figures on the right should be regarded as comparative rather than absolute but they do give an indication of progression with time and the last is within the range for twentieth century brick. (The average Schmidt hammer reading is denoted by "Q".) One factor in the increased brick strength is the introduction of higher kiln temperatures. The last value is not greatly different from those obtained with modern bricks.

Example 1.

Broughton House, 181 Clarence Street, Sydney, is shown in Section 9B. and is in its third life. The main brick structure was built in 1900 and was initially industrial in that it housed only a safe manufacturer and a hardware wholesale store. There was a bad fire in 1918 and the interior structure was then rebuilt in concrete. When the building reopened in 1920, it was used for offices: mainly for smaller organisations. A major refurbishment took place in the 1970s and it now is a block of apartments of some prestige. The quality of the brickwork appears excellent. This was one of the earliest examples of constructive reuse of one of Sydney's older commercial buildings.

Example 2.

For totally structural purposes, brick arches have long been a favourite form of construction by railway engineers. Section 9C shows a four-span bridge carrying the North Shore Line over Russell Street, Wollstonecraft, Sydney. This line was completed in 1893. The bridge has two spans of 9.1 metres and two of 7.6 metres.

This type of construction was used in the early 1920s for the goods line round Sydney to Darling Harbour from the north end. This required two large brick viaducts: one across Wentworth Park, Sydney, and the other across Jubilee Park in the suburb of Annandale.

Other properties of brick including its conservation may be found in:

www.buildingconservation.com/articles/brick/brickwork.html and

http://conservation.historic-scotland.gov.uk/inform-repairing-brickwork.pdf

MORTAR

Engineers customarily first think of mortar as the component of structural concrete other than the coarse aggregate. This uses Portland cement, but the use of this type of cement mortar for the repair of heritage structures has frequently proved to be disastrous.

One reason is that the low permeability of this type of mortar does not allow extrusion of fluid buildup within the main structural components, whether they are brick or stone. This means that there is a deterioration of these components even before the mortar, which is intended to be regarded as expendable and replaceable in a much shorter life span.

To eliminate this problem, it is necessary to revert to the once-popular use of lime-based mortar – or partly so -- which has a greater porosity, especially if the proportion of sand is much higher than is usual for concrete. One dictum is to aim for a permeability of mortar that matches that of the bricks.

Another attribute of lime mortar is that is more elastic than Portland cement mortar which means that, under various types of stress, the mortar will yield rather than the greater strength of Portland cement mortar causing the main material to fracture, if weaker.

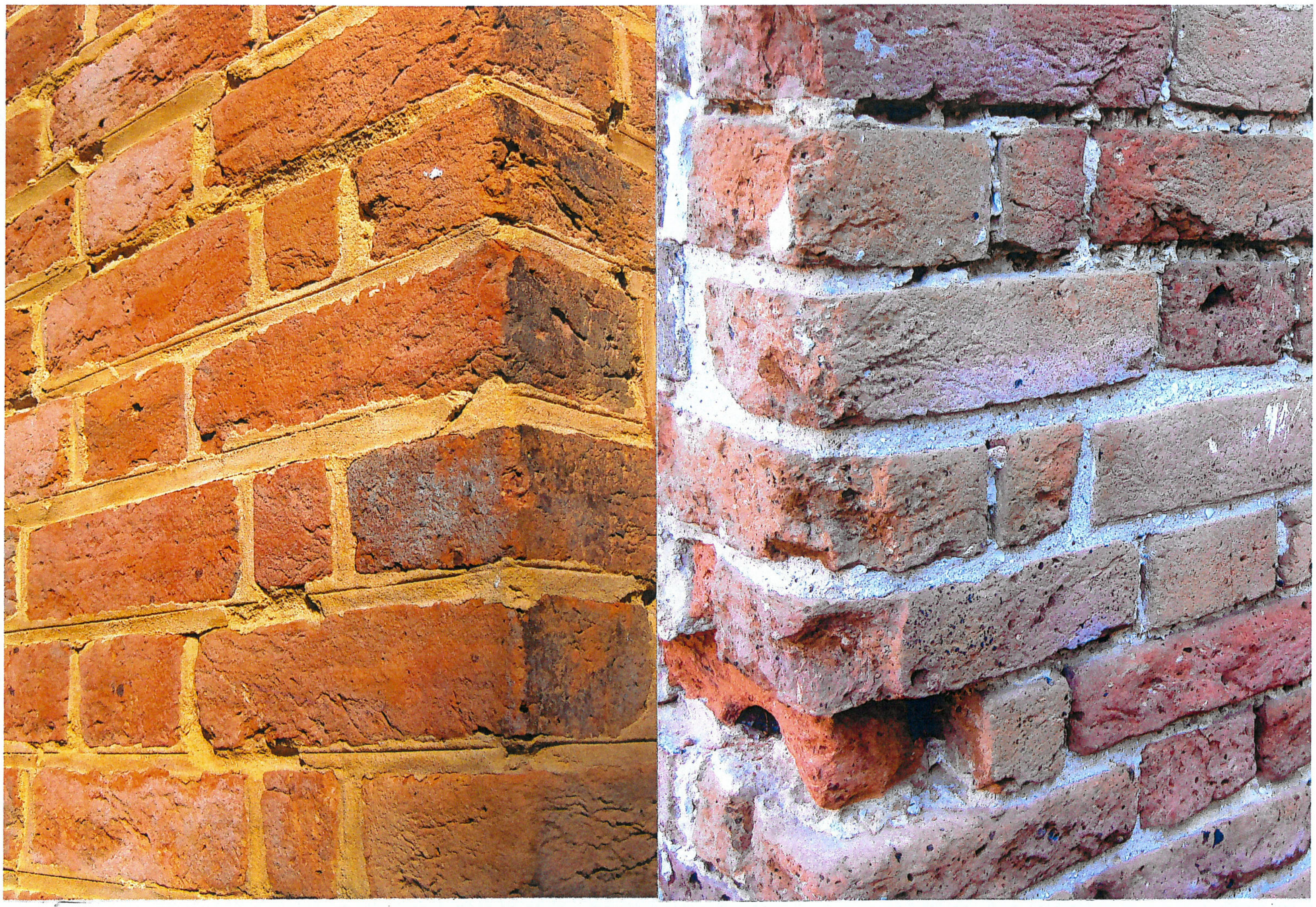
A thorough discussion of the topic can be found in:

http://conservation.historic-scotland.gov.uk/inform-lime-and-cement.pdf

The approach of selecting a type of mortar that matches the main structural material is given further emphasis in information provided by the City of Fremantle in Western Australia and this is given in Section 9D. Although it refers to limestone which is the common stone of the region, most of the content is applicable to other types of stone or brick.

A further viewpoint including details of materials and processes, can be found in:

www.gsa.gov/portal/content/111682



HYDE PARK BARRACKS, SYDNEY: BRICKWORK OF MAIN BUILDING (L) AND GUARDHOUSE, 1817 & 1819

Photos: IGB

BROUGHTON HOUSE, CLARENCE STREET, SYDNEY: BRICK, 1900

Photo: IGB

WOLLSTONECRAFT RAILWAY BRIDGE, SYDNEY: BRICK ARCHES, 1893

Photo: IGB

Heritage Building Conservation Technical Advice Sheet 4

Limestone walls need lime mortars

City of Fremantle

Relatively soft and porous materials like Fremantle limestone need mortars that are also soft and porous — lime mortars!

This technical advice sheet follows on from **Sheet 3 *Looking after limestone walls*** which should be read first. This sheet explains the traditional use of lime in Fremantle buildings, why lime is preferred over cement, the range of available limes, and those that should be used in repairs to limestone walls.

What is lime mortar?

Mortars and plasters consist of a binder, such as lime, and an aggregate, such as sand, that are mixed together with water to form a plastic (workable) material, which then hardens as it dries out in a wall. The lime binders that built Fremantle's older buildings were made by burning the local limestone in kilns to produce quicklime. The lumps of quicklime were then mixed with sand, and water was added to slake the lime to a fine powder, a process that gave off a lot of heat. Once slaked the mix was sieved if needed to remove any large lumps, wet again and mixed to the desired consistency and then left for a period of days to mature before use as mortar for laying stones and bricks. The same mortar was used for the base coats of internal plasters and external renders.

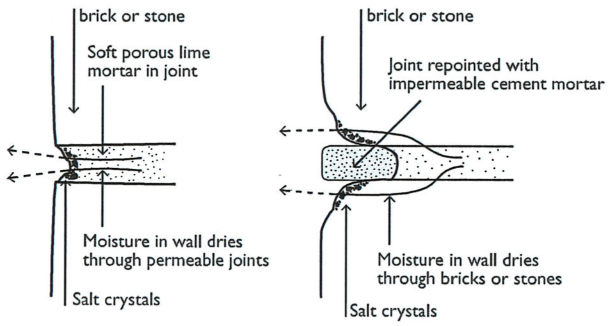
Traditional lime mortars are generally off white in colour though they may be light grey because of ash and also contain pieces of charcoal as residue from the wood-fired kilns. Small lumps of underburnt limestone are common in old mortars and are evidence that the quicklime was slaked with the sand (known as sand-slaking) in the way described.

What limes are available?

Pure limes — Today most lime is used in the dry powder form known as hydrated lime (or builders lime) that is widely available in hardware stores. Lime is also available as a directly slaked wet putty (lime putty). There are local producers of lime putty which is sealed in heavy duty plastic bags. Because of its finer particle size and greater workability, lime putty is often specified for conservation and repair work.

Hydraulic limes — Natural Hydraulic Limes, which are imported from Europe, can be thought of as a cross between pure limes (like lime putty and hydrated lime) on the one hand, and cements on the other; they make stronger binders than pure lime, but with significant permeability and elasticity advantages over cement. Natural Hydraulic Limes (NHLs) are widely used in Europe in new build and in the repair of older buildings. Formulated Limes (FLs), which are also imported from Europe, are pre-packaged mixes of lime and pozzolans.

Pozzolans — Pozzolans are fine-grained, glassy materials that when added to pure lime make a portion of it hydraulic, producing similar binders to natural hydraulic limes. It's possible to make your own lime and pozzolan mixes by adding small proportions of waste materials like fly ash and ground granulated blast-furnace slag (GGBFS) (which are both pozzolanic) to lime putty or hydrated lime.



Behaviour of mortar joints in limestone: left diagram shows a traditional permeable lime mortar, and the right diagram shows after repointing with an impermeable cement mortar. Salts crystallise where the moisture evaporates from the wall, decaying the lime mortar at left and the stones at right. It's much cheaper and easier to replace mortar than it is to replace stones. Repointing mortars should always be more permeable than the stones (or bricks).

Limestone walls need lime mortars

Which lime should I use?

Most of Fremantle's older buildings will have been constructed with relatively pure limes, and so it is appropriate to use pure limes like lime putty in repairs such as repointing of mortar joints (repointing is the process of replacing the outer part of a mortar joint with new mortar). Pure limes should be used whenever there are serious damp problems and salts that need to be managed (see Technical Advice Sheet 5 *Dealing with dampness in old walls*). This is because pure limes provide maximum permeability (breathability) which is so important to successfully dealing with damp issues. It may be appropriate to add a small percentage (5%) of pozzolan, such as fly ash or ground granulated blast-furnace slag (GGBFS) to pure limes for repointing more exposed walls with damp problems.

For more exposed walls generally, repointing mortars might be made of lime putty with 5–10% pozzolan, or of the lower grades of natural hydraulic lime (NHL 1 or NHL 2). NHL 2 mortars can be made more permeable and more workable by adding 10% of lime putty. The higher grades of natural hydraulic lime (NHL 3.5 and NHL 5) are too strong and not appropriate for repointing the mortar joints of most older buildings in Fremantle. Equally inappropriate, are limes with too much pozzolan, which is too reactive, as these will tend to block pores and so restrict the all-important breathing that enables traditional walls to work in the way they were intended (see Advice Sheet 3 *Looking after limestone walls*).

Why not cement?

As well as the conservation principle of matching like with like, there are good technical reasons for not using cement. Portland cement is very strong and ideal for making reinforced concrete, but it is not suitable for repairing old walls that were built with porous materials such as old bricks, limestone and lime mortar. This is because Portland cement is too strong, too brittle, too thermally expansive, relatively impermeable and it contains salts. While each of these factors are reasons for not using cement, impermeability is a key one. By blocking pores in the mortar and so forcing moisture in a wall to dry (i.e. to breathe) through the stones, salts will be concentrated in the stones leading to their early decay.

This effect can be seen in many walls that have been repaired with the best of intentions, but using the wrong materials. The new cement mortar stands proud while the stones erode (or fret) back from the surface leaving deep cavities. Eventually the stones will need replacement, which will be much more costly than replacing the mortar.

Two examples of the decay caused by impermeable cement mortar, which forces the limestone walls to dry through the stones. Salts accumulate in the stones which erode away, leaving the mortar standing proud. It's much cheaper and easier to replace mortar (repointing) than it is to replace stone.

One response might be to consider a composition mortar, such as a 1:2:9 mix of cement, lime and sand, thereby reducing the cement content and gaining some of the workability advantages of lime. But even mixes such as this are still too impermeable for use in old walls. Where there's a need for greater strength than pure limes can provide, then the addition of small percentages of pozzolans to pure lime, or the use of the lower grades of natural hydraulic lime are the appropriate response. However, it's important to be aware that strength is not often an issue when it comes to repointing thick stone walls. More important are good permeability, elasticity and compatible thermal expansion properties.

10. FOUNDATIONS

The supporting medium for heritage structures should always be an item for review when an assessment of a structure is made and reported.

The most obvious need for this area of examination is when apparent damage has occurred to the structure in question. The most frequently encountered case is when differential settlement has caused cracks in the building. There is thus some element of urgency for the carrying out of repairs to remedy the situation from the structural and appearance viewpoints.

When these aspects have been dealt with, consideration can then be given to how the materials will behave in future environments and whether additional protective measures need to be taken. Rates of deterioration of the original materials and changes in the nature of atmospheric attack are examples of such factors, with prediction of future settlement being in the category of foundations.

A third area for examination that is now often encountered is when a change of use is proposed that will increase the loading on the foundations. Development applications are regularly lodged that include the claim that the economic viability of the project is dependent on an increase of the size of the structure or the load it must carry. Typical of such projects are those that seek the addition of one or two floors to an existing building in order to make the enterprise worthwhile. What is happening at the top of the building often draws attention away from the need to examine the effect of the extra load on the foundations.

Different types of foundation have become familiar in courses in soil mechanics but some additional information follows. Insight into what may be discovered in foundations of the late nineteenth and early twentieth century and also the construction methods used is to be found in books such as “Foundations and Concrete Works” by Edward Dobson, 1903 (Forgotten Books print-on-demand).

Foundations on Rock

Early European settlers in the Sydney region would have benefited from the presence of sandstone near or at the ground surface. This had more than adequate strength for the support of buildings up to a few storeys in height. A well-known depiction of buildings in Sydney in 1848 shows little above four storeys. Thus the goal was simply to excavate to rock level and foundation problems would thereby be solved.

The process of quarrying for sandstone for building would however have been informative in that it would have become clear that the material contained stratification boundaries and other cracking defects so that care was needed in order to ensure that the load-carrying material was sound.

Eventually the realisation that the strength of the sandstone was indeed finite became the inspiration for strength tests carried out on samples of material from the projects. This evolved in the second half of the twentieth century into the science of rock mechanics, now fully in current practice. It follows that similar scrutiny should be applied to heritage structures which are likely to be impacted by new projects. An example of this is the large amount of tunneling that has taken place in the Sydney area and is likely to increase. Rock mechanics principles, including those related to both sound and fissured rock, are applied to determine the effects on existing structures.

Spread Footings

The principle of a spread footing is to increase the bearing area on the foundation material – and hence to decrease the stress – from that of a neo-concentrated load as applied by, say, a building column. This can be done by a strip footing of prismatic form or by a footing closer to a square shape in plan. Details of how this can be achieved are shown in the selection from old construction in Section 10A. It will be noted that only the Kent Street building bears the inscription: “Level of sound rock”. What material is beneath the others is unclear. It must be remembered that these drawings are from an era before the advent of soil mechanics as now understood and consequently details that would now be commonplace and significant are not always in evidence.

A system of spreading the load sometimes found is the use of grillages of metal beams or of timber sections.

Bearing Piles

The use of piles for foundations is very old, going back at least as far as Julius Caesar. There are many variations, one of which appears in Section 10A although again without much detail. It will be seen that this project was in Brisbane i.e., in an area less well endowed with rock near the ground surface.

The most common type of foundation pile to be encountered in heritage structures is the timber pile with turpentine *Syncarpia laurifolia* being the most favoured species with good strength properties. Turpentine is particularly valued in the marine environment as it has better resistance to borers such as the shipworm *teredo navalis.* Nevertheless, attack does occur, especially within the tidal range where there is a copious supply of oxygen, combined with the wetting and drying process. Below the mud line, however, there is hardly any mud line available, attack is minimal and the piles below this level continue to be fit for service. (Archaeologists continue to find wooden objects from ancient times that are in good condition through having been buried below the mud line.) A common procedure for repair is therefore is to cut off the piles just below the mud line and to splice on a modern section – not necessarily timber – to the original bottom section of the pile.

Repair procedures are described in;

www.woodcenter.org/docs/ICTB2013/technical/presentations/10_6_ID130_timber%20abutment%20piling_Dahlberg.pdf and

https://www.pavementpreservation.org/wp-content/uploads/presentations/Enchayan%20Timber%20Pile%20Repair.pdf

Metal Tube Piers

Large cast iron tube sections were used as piers for bridges until towards the end of the nineteenth century when the development of Australian industry enabled the production of wrought iron for this purpose. If there is any presence of salt water, it is necessary to be alert to the possibility of graphitisation of cast iron.

https://www.onlinepublications.austroads.com.au/items/ABC-AAI401-14

Settlement

The generalization that differential settlement is likely to cause more harm to a structure than a uniform, overall settlement of similar magnitude is a useful starting point in investigating the damage that has been sustained by a structure and future possibilities.

In structures such as low-rise buildings, especially those of brick or dimension stone blocks, patterns of cracking can occur that are normally identifiable in any diagnosis. Section 10B has illustrations of crack behaviour that are commonly found.

The phenomenon of "hogging" occurs when the ends of a building settle more than the middle. This often happens when construction has been on a clayey stratum that tends to dry out in times of low rainfall or drought. The resulting shrinkage of soil is independent of classical consolidation of soil by expulsion of voids by overburden pressure.

In hogging, the main pattern of cracks tends towards the formation of a broad letter "V", with the downward apex being in the middle of the building. The crack lines are interrupted and deflected by the brick and masonry units (which are usually stronger than the mortar) and by apertures such as windows and door openings. It may also be observed that the upper sections of the cracks are wider than at the bottom of the "V".

Deflections through "sagging" occur when, as shown in Section 10B, the middle of a building settles more that the ends. This would be in line with a normal analysis consolidation under a uniform load over a finite area. The general pattern of cracking in this instance tends towards the sloping lines of a wide letter “A”. The crack widths are usually larger at lower level than near the apex of the “A”.

Also shown in Section 10B is the potential for damage when trees are planted close to buildings. This structural distress is a common occurrence, for example, in the western and northern suburbs of metropolitan Sydney where deposits of shale and clay overlie the basic sandstone strata. In a dry spell, it becomes all too apparent that native species of trees have become all too efficient at extracting the maximum amount of water from the soil. The result is damage similar to that produced in the hogging case.

Some examples that follow relate to settlement of actual structures will illustrate extreme conditions, fortunately not found too frequently.

The **Palacio de Bellas Artes**, Mexico was completed in 1934 on the notorious volcanic clay of Mexico City. It has now settled about five metres below its original elevation.

http://elearning.autoisp.shu.edu.cn/tlx/pdf/54_94.pdf

https://prezi.com/6dr8qdfz6guf/palacio-de-bellas-artes

In spite of this spectacular movement, the building continues to function. As may be imagined, the landscaping of its immediate surrounds has been extensive in order to maintain access to what was originally ground floor level.

The building impresses by its chunky, compact nature and it is apparent that, in the early twentieth century, lessons had been learned from the previous behaviour of European buildings -- and presumably from those of the Aztecs – for builders to be aware of the nature of the former lake bed that was the city’s construction site. It would therefore have been good sense to design the whole structure with great rigidity, so that it would go down as close as possible to the behavior of a monolith.

The **Leaning Tower of Pisa** also survives because of the ingenuity of its builders who were aided by the long period of its construction: taking up to two centuries. It is true that there has been modern intervention to stabilise the angle of tilt but such a large angle (5.5 degrees, now reduced to 4.0 degrees) could normally be expected to produce internal stresses large enough to tear the structure apart.

www.slideshare.net/rhshah695/research-paper-of-leaning-tower-of-pisa

On looking at a cross-section of this structure, a standout feature is the thickness and apparent solidity of its base. The diameter of the base would probably have been influenced by the knowledge of the irregular lenticular clay/sand deposits beneath. It is clear that the designers were intent on producing as rigid a structure here as possible. Construction was interrupted a number of times and it was thus possible to take settlement and tilt progress observations. On the basis of this information, decisions were made to strengthen the lower storeys of the tower and, as an extreme measure, to actually introduce a bend in the tower in an attempt to keep the overall centre of gravity as far from the direction of tilt as possible.

These efforts proved to be successful but continuing monitoring in the twentieth century showed that the oscillatory nature of tilt (dependent on variations in the moisture content of the clay) had developed what seemed to be an ominous definite trend towards increasing tilt and the decision was therefore made in favour of major stabilisation – without losing too much of the tourist attraction.

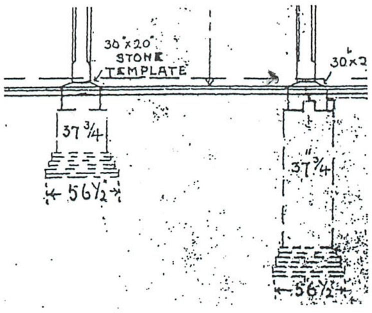
In contrast there is the behaviour of the **Bell Tower of San Marco** in Venice which, after four centuries of service, disintegrated rapidly into a pile of rubble in 1902.

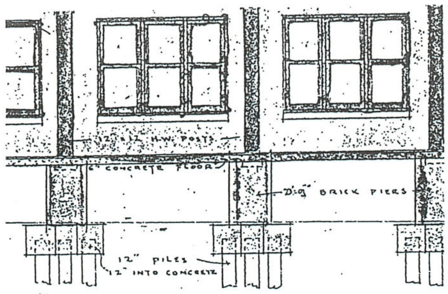
https://buildingfailures.wordpress.com/1902/07/14/st-marks-campanile

This structure can be described as being of a brittle nature, primarily of brick and stone. The final mode of failure was characterized by the tower being riven by vertical or near-vertical faults suddenly appearing through most of its height before the tower fell apart.

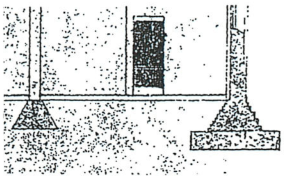
The differential settlement was not as large as in some similar structures that have survived but the nature of the construction even after allowing for deterioration, was such that it could not the unusual arrangement of internal stresses that were set up by the differential settlement. The tower was rebuilt, understandably with some structural modifications.

Concrete Piers on Brick Bases
Warehouse, Pyrmont & Allen
Streets, Pyrmont 1910

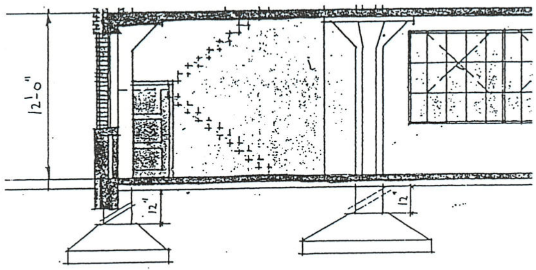




Piled Foundation with Concrete Cap
NZL Offices, Eagle St
Brisbane 1921

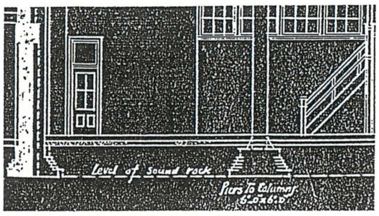


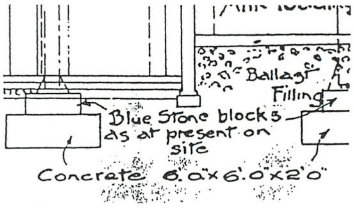
Outer Wall: Stepped Brick over
Reinforced Concrete
Inner Wall: Concrete Pyramid
Warehouse, Athlone Place
Sydney 1910



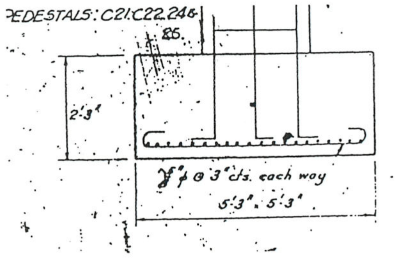
Concrete Flat Pyramids
Parke Davis Warehouse
Rosebery 1929

Built-Up Brick Footings
Warehouse, Kent Street
Sydney 1911

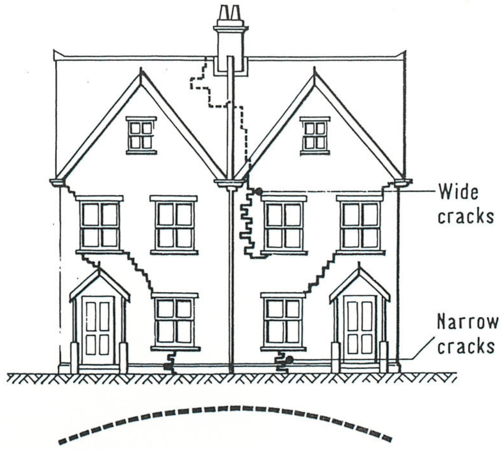




Bluestone Blocks over Concrete
Dairy Farmers Building
Ultimo 1910



Reinforced Concrete Footings
Anzac House, College St
Sydney 1954



(a) Hogging

(b) Local settlement

(c) Sagging

Cracking caused by foundation movement

CIRIA Report 111

11. INSPECTION AND RECORDING

WHAT IS THE CURRENT CONDITION OF THE STRUCTURE?

Before fieldwork, it is good practice to search for information that already exists in various sources concerning the heritage structure. This has the effect of reducing the number of surprises in the field and also creates an expectation of what is to be found, thereby lengthening the odds against something being missed and the necessity of repeat site visits. It is cheaper that way.

Formal lists

Section 13 includes some sources that would usually be the first port of call for background information on a heritage structure. Even though any one of these sources appears to supply a copious amount of information, all possibilities should be checked. This is because the entries in the different lists and registers are usually compiled independently and are frequently based on information from various origins. As a result, inconsistencies in information – including errors of fact – are frequently found and which need to be resolved.

Engineering Information

In New South Wales, the Local Government Act of 1909 decreed that drawings of new building construction and alterations were to be lodged with the local government authority, not merely for approval but for permanent retention in original or microform medium. Theoretically this is therefore an excellent source of information in the case of heritage buildings.

But there is a hazard in that there have been many amalgamations of the various authorities over the years, combined with other boundary changes. This has meant that there have been many transfers of documents between authorities, involving changes in geographical location. When dealing with affected areas it is thus necessary to be conscious of the histories of the LGAs in order to follow the document trail.

Early construction in New South Wales was under the direct colonial administration but from 1856 a properly constituted Department of Public Works became responsible for the construction of major items for public use. Most of the related documents were then handed over to the operating bodies but material on such projects is to be found in the State Archives and Records of New South Wales. This is a particularly useful source for survey plans.

The operating authorities, as stated, hold important original drawings of current active facilities e.g., documents on older bridges are with Roads and Maritime Services.

Occasionally there are very useful “windfalls” of documents such as when a century of drawings of significant projects of construction company Stuart Brothers went to the Mitchell Library of the New South Wales State Library. This last organisation is also a worthwhile searchable source for other projects.

In the 1970s there was publicity that a complete set of drawings for Sydney Opera House had been deposited in the vaults of the Bank of New South Wales (Westpac).

Community Resources

The archives of local historical societies (the names of which are listed with the Royal Australian Historical Society) can often produce relevant information on the structure under consideration. An example of this could be descriptions of flooding in the area.

Likewise, collections of photographs held in local libraries are useful in determining whether modifications have been made to the original structure.

The *Minutes of Proceedings of the Engineering Association of New South Wales* (1886-1920) and the *Journal and Abstract of Proceedings of the Sydney University Engineering Society* (1900-20) are held in electronic form by the University of Sydney Library. The *Transactions of the Institution of Engineers, Australia* for the following decade are held in electronic form by Engineers Australia, Canberra. These references could contain papers on or details of significant structures.

On Site

The extent and nature of the inspection and recording process of an engineering structure will, as explained below, depend on the ultimate purpose of the overall investigation. One possible starting point is to be found in the guidelines of the Historic American Engineering Record (HAER). This organisation was co-founded by the American Society of Civil Engineers in recognition of the increasing amount of rehabilitation and reuse of structures that engineers were being called upon to deal with.

It is useful to download these guidelines as a basis for how to proceed, covering a range of engineering items:

https://www.nps.gov/hdp/standards/haerguidelines.htm

(bearing in mind that "transit" is the American word for theodolite).

It will be found that much of the surveying work as described in this and other sources is at a standard covered in courses at university engineering level and will be familiar to those who have participated in these. In addition, a valuable guide to inspections of structures ancient and modern is: "Guide to surveys and inspections of buildings and associated structures" published by the Institution of Structural Engineers in 2008. Part 5 lists special points to watch for in different types of structures.

It often happens that all or most drawings or documents relating to a particular structure have disappeared. It is therefore necessary, depending on the objective of the study, to virtually start from scratch to produce dimensions and images for the record. Under these circumstances, the term "measured drawings" will be encountered which virtually describes the process. Drawings of the subject are re-created using a large number of measurements in which a tape measure figures prominently. It will be seen that Part 4 of the HAER guidelines has information on this procedure but there are also standards for the final products in a document produced by the HAER in co-operation with the Historic American Buildings Survey:

https://www.nps.gov/hdp/standards/HABS/HABSDrawings.pdf

Additional advanced techniques are described in "Measured and Drawn" (English Heritage, 2010).

Not many mobile phones currently on sale have cameras with the necessary resolution to produce photographs of sufficient quality for technical reports of for enlargement. A camera with a sensor of a minimum of ten megapixels is required. All cameras now being produced with this resolution or better are equipped with a "macro" setting for close-ups, which is an essential capability for this work and which mobile phones generally do not have without a supplementary lens.

In determining how much information is required from a particular field inspection and investigation, it is instructive to look at three of the possible scenarios that could be encountered.

A.

A one-off, thorough inspection of a heritage structure is sometimes commissioned with a primary aim of predicting how long the structure can continue in service and whether some precautions or constraints are to be applied in its use. There would also be some recommendation as to when the next similar inspection should take place: often many years in the future.

A useful example of this occurred about the time of the celebration of the centenary of the famous Forth Bridge in Scotland which took place in 1990. After a very thorough examination, the Bridge was declared good for another thirty years. The only significant constraint imposed was a continuation of the rather modest speed restriction on this well-used railway structure.

For clarification, it is useful to contrast the above approach with the routine structural inspection of structures, both heritage and non-heritage, adopted by authorities. In such cases the level of inspection is not as intense but is carried out at much shorter intervals. With large owner authorities, the inspection members of staff for this purpose are frequently permanently employed: working around a regular inspection cycle of structures.

A useful illustration of this is to be found in the VicRoads "Road Structures Inspection Manual" which can conveniently be found with others via:

https://www.google.com.au/#q=road+structures+inspection

A particular item of interest in this publication is that it includes a set of recording forms in Appendix A2. On completion of the inspection, if there was no matter that required attention or remedial work, the forms would be filed away. (The unfortunate collapse of a large steel signal gantry over the railway at the busy Clapham Junction, London, in 1965 was due to such reports being filed away without further action, even when the increasing defects had been conscientiously reported by inspectors for some time. The lesson from this is that proper administration procedures should be in place to react to reported defects and to carry out the necessary repairs. Someone has to read the forms.)

The VicRoads forms are of a general nature and if they are to be applied to heritage structures, lack a series of entries that relate specifically to heritage matters – perhaps as a first sheet in a suite of forms. These items would include the location of plans and progressive photographs; dates of original construction and modifications; dates of references in Trove &c; registers and lists in which the subject appears; names of previous owners and operators; the existence of previous heritage consultants' reports and the existence of conservation management plans. Aside from a suggestion of the time for a future inspection, the overall condition of a structure is often reported by an adjective such as "excellent", "good", "fair" or "poor" although in the heritage field: "out of service" and "ruinous" are also used to extend the range. See also Section 5E.

A good supporting reference in this activity is the "AREMA Bridge Inspection Handbook" of the American Railway Engineering & Maintenance Association. A valuable feature of this publication, which deals with steel, concrete and timber railway structures, is that it contains a copious collection of photographs of defects and failures that have occurred in these three materials.

Although recording forms are mentioned in the above publication in the list of equipment required for inspection, no actual forms are offered. However, AREMA's "Manual for Railway Engineering" does have forms in the concrete structures chapter, currently Chapter 8 in volume 2, but understandably are for routine inspections, without a section related to heritage as intimated above.

B.

The second type of inspection is usually undertaken on co-operation with persons who possess expertise other than in engineering. The purpose of this kind of venture is usually for the preparation of a conservation management plan (see Section 13) or as a special review in the procedures for a significant development.

In such cases, engineers need to collaborate with heritage consultants, architects, archaeologists, conservators and historians. Discussions will result in determining the extent of the engineering investigation that is most efficient in producing the essential information, bearing in mind that there is a cost for professional services.

C.

A further instance of co-operation between the engineer and other professions occurs on the occasion of the assembling of a submission of an item for inclusion in a state heritage register or similar. On inspecting a number of successful entries in these registers it will readily be seen that these documents are overall very much smaller than full technical reports. The amount of engineering input is correspondingly less in proportion. Leading dimensions, type(s) of structure, materials, dates and modifications are customarily found but the emphasis in this type of submission is usually biased towards historical and cultural aspects, although there is usually a requirement for a pronouncement on the condition of the item as mentioned above. There is most scope for the inclusion of engineering data in the "Description" sections of submissions as indicated in:

www.environment.nsw.gov.au/resources/heritagebranch/heritage/listings/SHRNominationsGuideline2006.pdf

In connection with all types of inspection, "Recording Historic Structures", sponsored by the National Park Service of the USA (Wiley, 2004) is an important reference. One of the collaborators in this publication is the HAER and there is an extensive chapter on measured drawings. There are also case histories and examples in the fields of historic bridges and structural systems. If this publication has a fault, it is that it could deter people because of the very high quality and elaborate nature – and high labour content – of most of the drawings. Drawings of good, basic standard from conventional engineering and architectural practice are usually quite satisfactory for heritage records.

The AREMA inspection handbook contains a formidable array of the apparatus that a railway bridge inspector might need, to the extent that a very large vehicle would be needed to transport it all. Other schools of thought show an inclination towards demonstrating that few items of equipment are required: a tape measure, surveyor's level, a quality camera and a few miscellaneous items to fit the task in hand.

For general use, a practical balance could be obtained by using the AREMA list as a type of checklist and only extracting for use those items that are likely to be needed in a particular project such as could be indicated in the three variations mentioned above.

Cracks

There is one special area in heritage structures that is common to most materials: the incidence of cracking. After the detection of a crack, there is the need to measure its width – probably at a number of different points – and the change in width, with the possibility of some rotation, over a period of time.

Commercial literature is often helpful in describing equipment, as exemplified in Section 11A.

Of startling simplicity is the "Crack Width Meter" as illustrated at the bottom right of the page. This device carries a series of black lines of different thicknesses for contact comparison with cracks. This approach has been found to be ergonomically easier to use and quicker than attempting to measure crack width directly with a ruler scale. The extreme portability of such a device is also noted: credit card size.

Closer examination can be achieved by simple magnifying apparatus such as the "Measuring Magnifier" and, for greater magnification, the "Field Microscope". Both of these incorporate a measuring graticule for greater accuracy. It should be noted that all the above devices rely on the ingenuity of the observer to mark the positions where the crack width readings were taken. This is necessary where repeat readings are taken in order to record crack progress.

Some success has been obtained by using the lower magnification region of the range of USB microscopes that are now on the market. These can be combined with the graticules of measuring microscope glass slides, the graticule side of the slide being pressed against the material surface to maintain focus. The graticule slide can also be permanently fixed to the microscope body where its design permits. (This eliminates the zoom facility but the commercial reality is that these devices are now very inexpensive and a second one could be purchased.) In either case, an image can be sent to a portable (field) version of a computer screen in order to assist manipulation and a permanent record made by pressing the photo button on the microscope body. Some microscopes have built-in software for measurement.

If permanent intrusion of space in the structure can be tolerated and an area found that is remote from the elements and vandalism, a device such as the one shown under "Crack Monitors" can be used. This type uses two flat "arms": one cemented to each side of the crack under examination. Where the arms overlap in the middle, there is a graph grid on one arm and an index line on the other. The variations in crack width can thus be read off the grid, which can also be adapted to detect relative rotational movement. It will be noted that that the problem of locating the positions for successive readings is eliminated by this device which is to be seen in the investigation into the "Sinking Tower" of San Francisco:

http://www.domain.com.au/news/san-franciscos-750m-millenium-tower-is-sinking-who-will-pay-for-it-201702012-gu45q7/

Less conspicuous is the apparatus described as "Digital Position Strain Gauge Deformation Meter". Expendable metal discs, each with a slight recess in the centre, are cemented on opposite sides of the crack. Periodic readings are taken by inserting the points of a bar-type gauge into the recesses.

Ultrasound is also used in the study of cracks as mentioned in Section 12.

Digital Position Strain Gauge Deformation Meter

The Digital Position Strain Gauge [DPS] consists of a digital dial gauge fixed to a bar. A fixed conical point is mounted at one end of the bar, and a moving conical point is mounted on a pivot at the opposite end.

The pivoting movement of this second conical point is measured by the dial gauge.

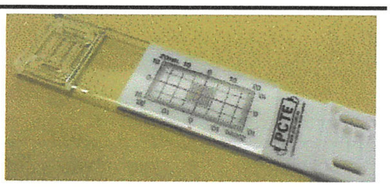
A setting out bar is used to position pre-drilled stainless steel discs which are attached to the structure using a suitable adhesive.

Each time a reading has to be taken, the conical points of the gauge are inserted into the holes in the discs and the reading on the dial gauge noted. In this way, strain changes in the structure are converted into a change in the reading on the dial gauge.

The gauge has been designed so that only minor temperature corrections are required for changes in ambient temperature, and an Invar reference bar is provided for this purpose.

Crack Monitors

On some structures the rotation at cracks is also significant. Crack Monitors are designed for at a glance measurement.



This gauge is specifically designed to measure rotation, transverse and longitudinal movement. Special fittings are available to measure external and internal corners. The crack monitor is:

- Made of polycarbonate
- Used for measuring movements
  - Horizontal ± 20 mm, vertical ±10 mm.
- Reading accuracy of:
  - ± 0.5mm on Grid

Measuring Magnifier

Crack widths are normally limited to 0.2mm or 0.3mm in concrete structures. This inexpensive crack width measuring device enables accurate determination of whether cracks exceed this limit.

- Magnification 10x
- Measuring range 20 mm x 0.1 mm
- Field of View 32mm
- Special design permitting to read on light and dark objects
- Plastic case.

This loupe also comes in a self-illuminating model. Powered by two c-cell batteries this model can be used in those poorly lit areas where the natural light is dim or non-existent.

Field Microscope

The field microscope is a small sized lightweight and conveniently portable microscope. Designed to cover the range between high grade heavily equipped microscopes and measuring magnifiers. With a magnification of 50 times this microscope can combines a calibrated focusing ring allow the depth of cracks to also be accurately measured.

- Magnification 40x
- Measuring Range 1.6mm x 0.02mm
- Field of View 1.7mm
- Optional Light Holder

Crack Width Meter

The crack width meter is used as a comparator to give an approximate crack size during visual surveys.

- Made of durable plastic
- Graduations 0.1 - 2.5mm

12. TESTING

The traditional civil engineering procedure involves the testing of the materials to be used; the insertion of these materials properties – which may be incorporated in standards – into the design process and then the implementation of the design in construction. The properties of the materials could also be monitored during the construction phase.

It will readily be seen that the engineer who has the task of determining the condition of a heritage structure works under some levels of handicap. In most cases there is a great shortage of information about the properties of materials used. With the passage of time, documentation tends to disappear and living memory, for what it is worth, has long gone. There is also the fact that quality control of materials and their use was mainly not up to the standard demanded today. The regular appearance of exciting new materials brings a burst of confidence in the resulting gains without appreciation of a proportionate need for careful monitoring.

There is also the very apparent process of deterioration of the materials over time, whether this occurs from action by the natural elements or by the ever-ingenious efforts of mankind.

Such difficulties have, however, themselves been influential in encouraging the development of techniques and equipment suitable for the assessment process. Heritage structures of value obviously should be tampered with as little as possible (see The Burra Charter, dealt with in Section 15) so that, in the lists of tests referred to below, non-destructive testing (NDT) figures prominently.

A list of possible tests and their applications will be found in Appendices 7 and 8 of the IStructE "Appraisal of existing structures" (Reference 1 in Section 16). A listing of possible tests is also given in Part 3.7 of the ASCE publication: "Guideline for Structural Condition Assessment of Existing Buildings" (Reference 2). Parts 4.2 to 4.5 of this publication also have grids showing the possible applicability of the various tests to some materials and components.

Where documentation has been lost, chemical analysis – requiring only a small quantity of material – has been useful, for example, in determining the very basic question of whether a structure is made of steel or of wrought iron. (The transition took place over a long time span, with related loss of documentation.)

Mechanical Testing

The traditional procedures for determining tensile strength, compressive strength, modulus of rupture in bending &c are included in the lists in the two references mentioned above but, as has already been noted, existing structures have obvious limitations on the availability of specimens to contribute to the knowledge of properties within the structures.

But opportunities do arise and it is necessary to be alert to their occurrence in order to monitor the condition of the total structures.

Sections 3 (Example 3) and 3A refer to the High Level Bridge in Newcastle, England. The aspect mentioned was that of the cast iron arches of the six main spans and their soundness after one-and-a-half centuries because of the compressive forces therein. But this same bridge also has cast iron cross girders which understandably were a matter of more concern. It was possible to remove one of these girders, test it to failure and repair it for reuse.

Major alterations to St Pancras Station, London, meant that a number of the original 720 cast iron columns supporting the main deck were no longer required. This was a great windfall from the point of view of testing because it meant that an extensive laboratory programme could be carried out which gave valuable information on the remainder of the structure and also concerning cast iron practice in the 1860s.

Roads and Maritime Services of New South Wales has, in its charge, a great many timber bridges: mostly made of ironbark. Their maintenance programme means that, from time to time, elements of these structures develop local faults and need to be replaced. (In fact, the Allan type truss as shown in Section 7D was designed to facilitate this process.) It has been possible to obtain some of these discarded components and test them, as part of a useful monitoring process of structural members at the end of their original life. Some of the cast iron components of these timber structures have become damaged in service and have had to be replaced, thus providing material for testing for the properties of cast iron used by foundries in the 1890s and early twentieth century.

The replacement of dimension stone in structures, such as those made of the sandstone of the Sydney area, means that the removal of blocks in diverse places produces specimens also likely to be indicative of the properties of their neighbours.

As in the case of St Pancras Station, many structures – even heritage structures – are subject to some form of alteration and original material thereby becomes available.

For timber testing, the Australian standard is AS/ANZS 4063.1:2010 but local preference has been for standards produced by the International Standards Organisation, particularly ISO 3133/ISO 13061-3 for modulus of rupture in bending and ISO 13061-17 for compression. The American Society for Testing and Materials ASTM D143-14 covers a range of tests for timber properties.

Tests for stone have been drawn from the ASTM tests compilation CD: “Dimension Stone”.

The Electron Microscope

A most useful activity with this apparatus has been the examination of the microstructure of grey cast iron referred to above. Comparison collections of images of different carbon arrangements are given in Australian Standard AS 5049-2002/ISO 945 in contrasting black-and-white. Half-tone B/W versions are available from ASTM.

The laminar structure of wrought iron is detectable in electron microscope images.

NDT1: Impact Energy

The concept of measuring the energy absorbed by the surface of a material as a result of impact and then using this quantity as a measure of soundness was taken up several decades ago in the production of the Schmidt Hammer. The material that was the incentive for the development of devices for this function was concrete in that it aimed to provide a measure of some type of strength value after the concrete had set, without destructive procedures such as taking cores.

If the Schmidt Hammer impact is matched to the strength of the concrete and the impact surface is broad enough, for all practical purposes there is no damage to the material. It follows, however, that the depth of the material that can be considered to be under investigation is limited to only several millimetres below the impacted surface. Relatively recent research into the test has a conclusion that the test, while useful in many respects, should not dictate the acceptance or rejection of a concrete section. This is something that prudent engineers have been aware of for some time.

Whist this depth limitation may be viewed as a disadvantage in some sectors of engineering inspection, it is a useful attribute in the investigation of heritage structures. Some common materials undergo deterioration in the surface layers (e.g., Stone in Sections 8 and 8E) and therefore it is precisely this region that is under examination, rather than deep into the mass of the material.

The original Schmidt Hammer, which is still being sold and for which there are a few instructional videos on the web, has evolved into the much more sophisticated Silver Schmidt type. (There is some indebtedness to commercial literature for a good description of this instrument and reference should be made to Section 12A.) The standard type, such as could be used for hardened concrete is designated as Series “N”, referring to normal impact energy. There would probably be qualms about using this energy on a heritage structure and it is fortunate that the manufacturers have introduced a low energy Series “L” Silver Schmidt. The impact plunger in normal use is the end of a 15mm diameter steel cylinder but, particularly aiming at the lower force range in more delicate materials, a “mushroom” plunger is available which has a broader, flat spherical surface. The mushroom plunger has been used on sandstone and brick without detectable damage to the materials.

Each reading customarily only takes a few seconds but, because of scatter, it is necessary to take twenty or thirty readings in order to obtain one value. (The Silver Schmidt contains software that eases the arithmetical burden.)

The reading on the instrument display is a "Q" value related to energy which is the axis of a graph of Q versus compressive strength obtained over an extensive research programme. It will be seen that, in investigating heritage structures, a more useful approach than seeking purely compressive strength would be a comparison of the readings obtained from an exposed and deteriorated surface with those from a freshly cut surface from the interior.

For detailed operation:

https://www.youtube.com/watch?v=FKCoz3tswIw

NDT2: Ultrasound

The application of ultrasound in fields other than engineering is well known. The frequency of 50 kHz is commonly mentioned in literature and this is the frequency used by the Steinkamp BP-5 which is a very basic unit and which has featured in research activity in this field. This apparatus is shown in Section 12B. Its principle is that of an ultrasound transmitter and receiver together with a timer to measure the return interval of the signal.

In the photograph, the transmitter and receiver probes are held on the same surface of a sandstone block which contains a crack between the probes. The timer is displaying an interval of 22.9 milliseconds between the signal's departure and return. Another common arrangement is for the probes to be pointing towards each other on opposite sides of a wall or the upper and lower surfaces of a slab (a). The probes can also be at right angles to each other in investigating a corner or edge (b).

More sophisticated versions of ultrasound equipment are available that produce screen displays. Some of these have simultaneous multiple transmitters/receivers.

NDT3: Stress Wave Testing

The impact of a hammer on an artifact produces waves of different types. In the simplest form, audible signals generated by a small hammer convey valuable information to the experienced observer as to the soundness of the material. This approached was used successfully recently in the appraisal of the 1779 cast iron Iron Bridge at Ironbridge in England.

www.bbc.com/news/uk-35674039

More sophisticated types of instrumentation, although still using a recognisable hammer, have now evolved and a good guide for the use of these for timber bridge testing can be found in:

https://www.treesearch.fs.fed.us/pubs/5886

Particular mention should be made of one variation within this testing approach:

www.scotts.com.au/papers/download/BSamali.pdf

This has been used extensively on a large number of the timber beam bridges that are extant in New South Wales. A measure of its success is that the number of genuine defects that have been discovered is much greater than was suspected prior to testing. It will be seen that, in this case, the shock is delivered by impact from an implement of sledgehammer size. The process has been refined so as to reduce the time of each test to little more than half-an-hour, enabling a number of tests to be carried out in a working day. This is an important factor in reducing overall cost because of the large amount of travel time to the remote areas where these bridges are located. A commercially produced version of such equipment is cited in Section 12C.

For concrete: https://www.youtube.com/watch?v=fcpFjcrRbuU

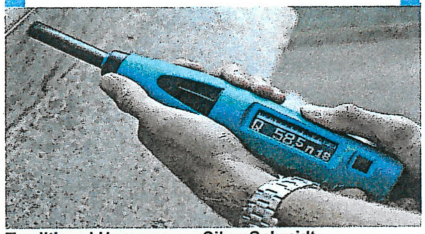
NDT4: Ground Penetrating Radar (GPR)

The title of this technique has become something of a misnomer because, although the original application was indeed to detect anomalies below a soft ground surface, it is now used for the scrutiny of other materials.

Referring to Section 12D, the upper left photograph shows a hand-held GPR unit being rolled along the underside of a prestressed concrete beam. The large wheels track the horizontal axis of the plot which is shown on the screen in the upper right photograph. The characteristic trace produced by a “point” object or one of small, finite size such as a reinforcing rod is a hyperbola with its apex pointing towards the radar source. Multiple variations of this can be seen in the traces on the screen and also hints of the prestressing duct. Experienced operators can extract information from such a display in its raw state but software is available for conversion of the signals to more generally comprehensible images. In the photograph at lower left it is seen that a scan of a surface grid can be converted to a recognizable grid of reinforcing bars. A live electric cable, cutting across the grid, shows up quite clearly.

A traditional GPR unit is illustrated in the lower right photograph. The yellow GPS receiver head is conspicuous. Aside from detecting items below ground in open areas, these devices can be run close to a heritage structure in order to investigate the outward extent of foundations.

SilverSchmidt ST and PC – Rebound Hammer



Traditional Hammers vs SilverSchmidt

The classical hammers suffer from the following insufficiencies:

1. The rebound value is dependent on the impact direction.
2. The rebound value is affected by internal friction.
3. Limited tightness of sealing causes premature loss of accuracy.

The unique design and high quality construction of the SilverSchmidt address all of these issues and makes rebound hammer testing quicker and more accurate than ever before. Conversion curves are provided for a wide range of compressive concrete strength, including low and high strength concrete fc <10 MPa (5MPa using Mushroom Head with the Type L) and up to 100MPa. Conversion curves for different types of modern concrete are preset in the Silver Schmidt, based on tests performed by an independent institution

Dependable Measuring Results

- High accuracy due to differential optical absolute velocity encoder
- Measurement inherently independent of impact direction, meaning no corrections necessary
- Built-in correction for carbonation and form factor gives increased test accuracy and dependability of test results
- Registration of true rebound coefficient yields extended resolution across a wider range
- Silver Schmidt can also display the classic R value

Controlled and Extended Functionality

- Automatic control of functionality by monitoring impact energy
- Low power consumption, high capacity lithium-ion battery
- The Mushroom Head attachment has a larger surface area and is used for early age strength or softer materials

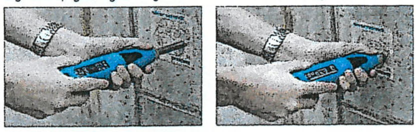
Applications

- Suitable for testing a wide variety of concrete, mortar, rock, paper and plastics
- Ideally suited for on-site testing
- Handy for difficult to access or confined test areas (i.e. working overhead)
- Especially convenient for testing on tunnel linings as measurements are independent of impact direction

Operation

- Simple operation with the "one button" user interface
- Language independent through the use of graphic user interface
- Automatic conversion to the required measurement unit (MPa, kg/cm2, psi),
- Various statistics to comply with standards or user specified procedures
- Custom presets of test parameters for various testing scenarios can be stored and later recalled
- Quick review of previous measurements

Ergonomic, lightweight design facilitates reliable measuring



1. Place the unit perpendicular to the test surface

2. Load the unit by pushing it towards the test surface

3. Impact is triggered when the end position is reached

To obtain a reading in units of compressive strength select:

- Desired unit
- Length of series and averaging mode
- Carbonation depth (if applicable)
- Conversion curve for concrete mixture
- Form factor

Perform a test series of specified length. Manual cancellation of obvious outliers is possible. At the end of the series, the instrument will display the average converted to the desired unit.

CONTINUED ...

Measuring True Rebound Coefficient ("Q"-value)

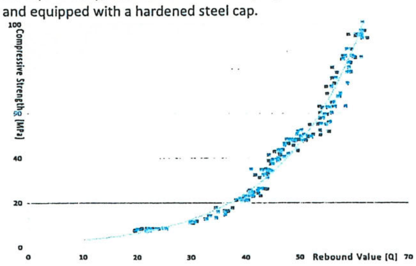
The classic "R"-value is the mechanical travel of the mallet on rebound. It is affected by its friction on the guide rod, the friction of the gauge, gravity, the relative velocity between unit and mechanical parts. This is true for all concrete test hammers currently on the market.

The Silver Schmidt acquires the "Q"-value by measuring the velocity (V) of impact and of rebound immediately before and after the impact. The "Q"-value need not be corrected for impact direction. There is a clear relationship between the "Q" and the "R"-value.

The "Q"-value [=rebound V divided by inbound V] represents the physical rebound coefficient. It is virtually free of all the above error sources. It is thus the indicator of choice to be used as a basis to convert to compressive strength.

New Improved Plunger

The lightweight hybrid design of the impact plunger is made from aerospace alloy, matched to the elastic properties of the concrete and equipped with a hardened steel cap.

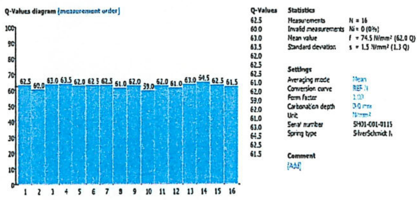


Independent validation testing by BAM in Berlin has shown the SilverSchmidt to have less dispersion than the classical hammer over the entire range.

Hammerlink

The ST Model Silver Schmidt only has the capacity to display the last 20 results. The PC Model Silver Schmidt on the other hand is the extended data logging model, it can log 1300 single impacts or over 465 measurement series, each with 10 readings. The data is then downloaded to PC using the Hammerlink application and a USB cable.

- Extended memory usage
- Rapid uniformity assessment with the summary view
- Sorting of data
- User-defined conversion curves
- User-defined statistical methods
- Highlighting of mean, median and outliers



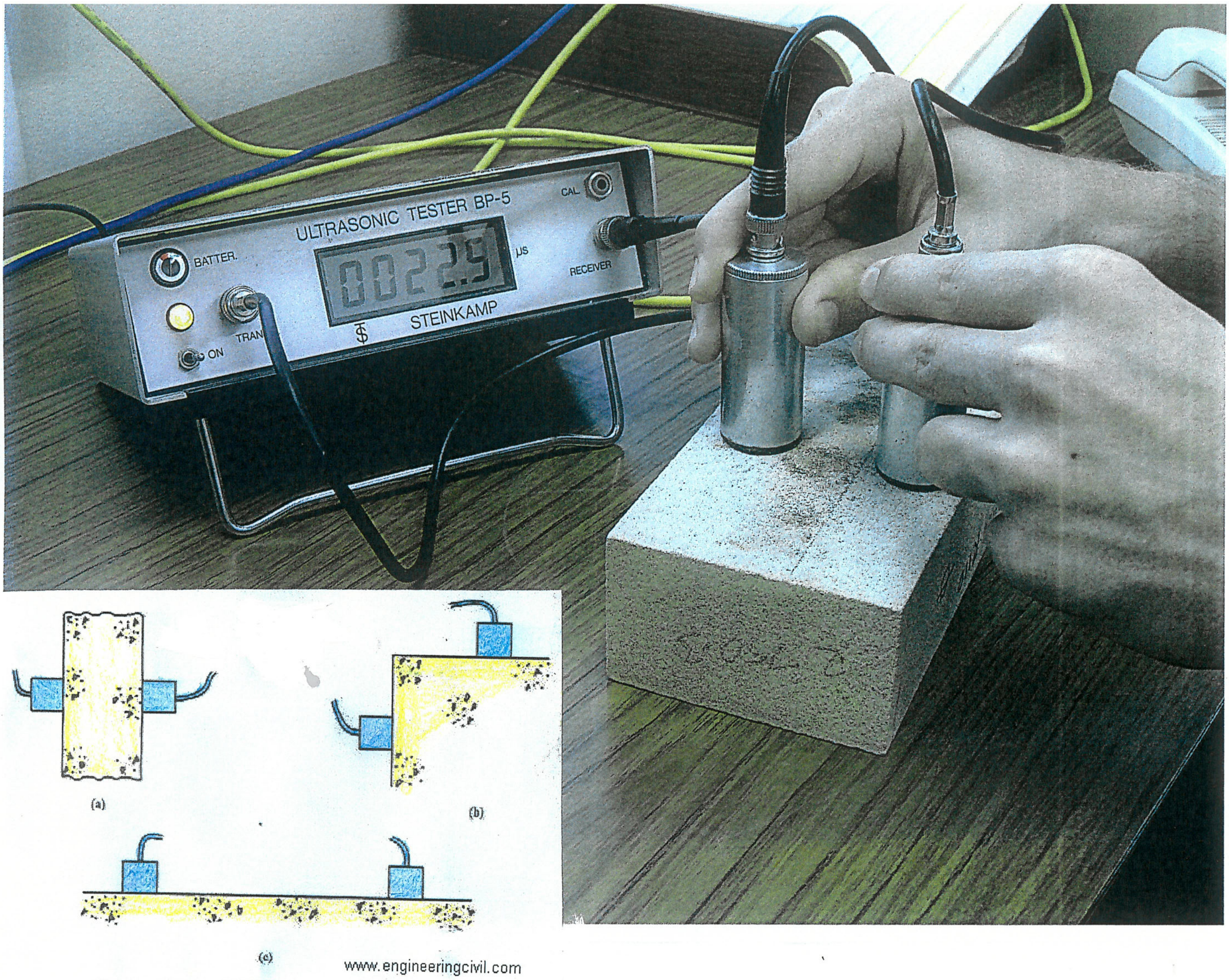
- Carbonation correction
- Export to third party software

Compliance with Industry Standards

Data collection and processing of test results comply with major industry standards: EN 12504-2, ENV 206 ASTM C805, ASTM D5873 (Rock), BS 1881, part 202

Technical Information

Mechanical data	Type N	Type L
Impact energy	2.207 Nm	0.735 Nm
Hammer mass	135g	135g
Spring constant	0.79 N/mm	0.26 N/mm
Spring extension	75 mm	75 mm
Housing dimensions	55 x 55 x 255 mm (340 mm inc plunger)	
Dimensions (plunger)	105 x ø15 mm	
Weight	570 g	
Electrical data Display	17 x 71 pixels; graphic	
Power consumption	~13mA measuring, ~4 mA setup and review, ~0.02 mA idle	
Accumulator duty	>5000 impacts (before recharging)	
Charger connection	USB type B (5V, 100 mA)	
Range Comp strength	5 MPa to 170 MPa (with Mushroom Head)	
Operating temperature	0 to 50 °C	
Storage temperature	-10 to 70 °C	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Model 2303 / 2304 / 2305
Modal sledge hammers

Features

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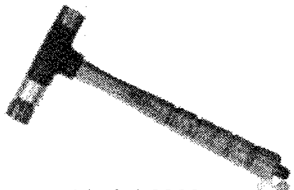
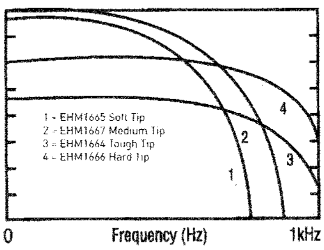
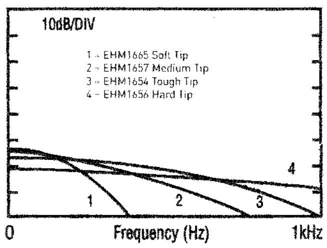
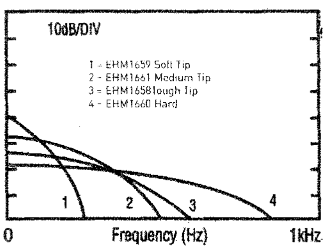
- Four interchangeable faces
- IEPE (Isotron®)
- 1, 3, and 12 pound heads


Model 2303


Model 2304







Description

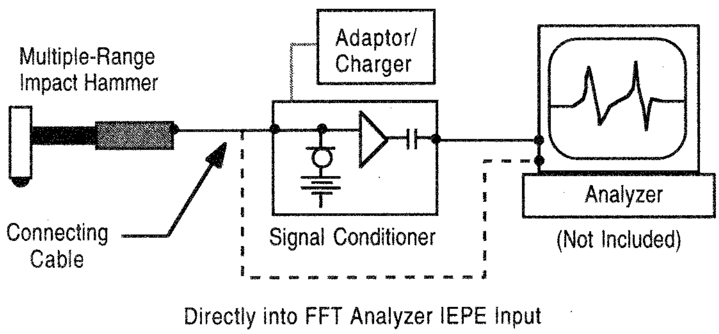
Endevco's instrumented sledge hammers provide a convenient and economical means of exciting large structures. The one and three pound hammers are designed for exciting such structures as machinery, shafts, large beams, pipelines, storage tanks and other large structures. The 12-pound hammer can be used on larger structures including bridges, buildings, decks and floors.

The modal hammer excites the structure with a constant force over a frequency range of interest. Four interchangeable tips are provided which determine the width of the input pulse and thus the bandwidth. Typical force spectra produced with different tips are shown on the right.

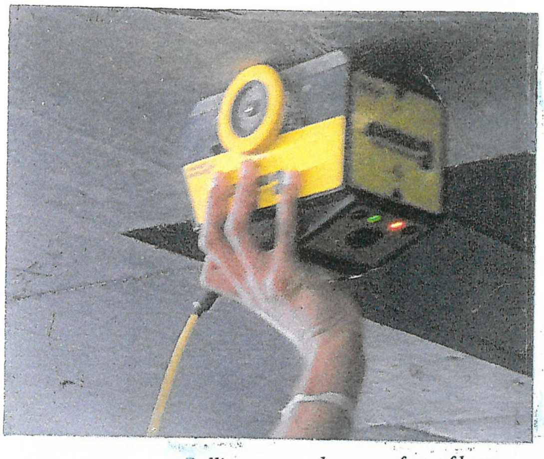
Each hammer is constructed with a hardwood handle and a cast iron head. The electrical cable is routed internally and terminates to a BNC connector on the end of the handle.

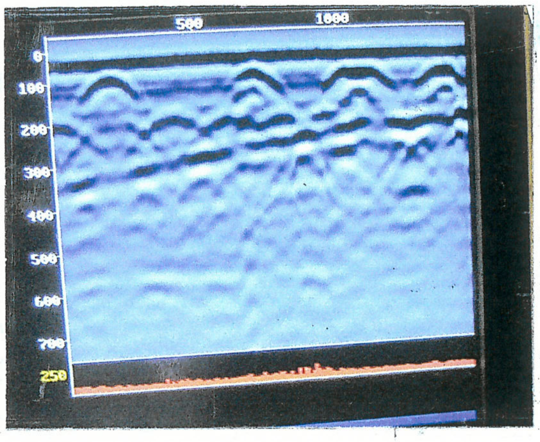
The hammer features an Isotron® impedance converter providing an IEPE output which is compatible with most FFT analyzers and data acquisition systems.

Endevco's 4416B single channel signal conditioner or the model 133 three channel conditioner are recommended for use with this hammer series. To excite smaller structures, see the 2301 and 2302 hammers.



MEGGiTT
smart engineering for
extreme environments





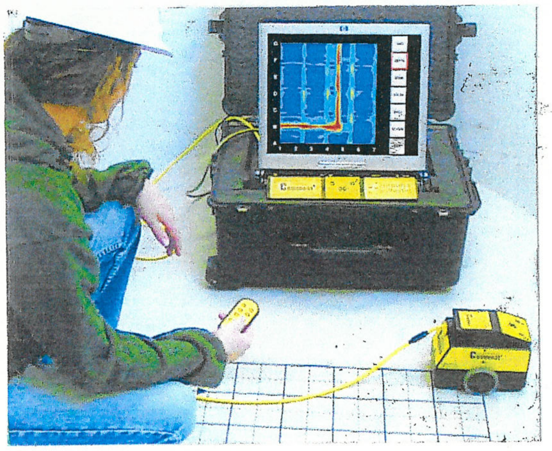
Rolling scan on lower surface of beam

Hyperbolae images on "point"/finite objects

GROUND PENETRATING RADAR TESTING

Conversion of grid scan

Field GPR unit with GPS locator



13. REPORTS

As mentioned in Section 11 dealing with inspections, the type of report that is the eventual goal has a strong influence on the conduct and integrity of the inspection and early investigation. Referring back to that section, three of many possible report types were mentioned.

Useful comments on the process can be found in the chapter on the structural engineering section contained in "How to write a historic structure report" by D. Arbogast (Norton, 2010). Perusal of the overall contents of this publication provides a reminder of the wide range of expertise and disciplines that could be employed in the process.

Strictly Structural

With regard to the detailed structural type of report, it was also mentioned in Section 11 that Chapter 8 on concrete structures in Volume 2 of the AREMA "Manual of Railway Engineering" contained forms for the recording of inspections of concrete structures. The steel structures chapter, No.15 in the same volume, provides sample diagrams of many types of steel structures found in railway practice in order to provide convenient ways of referencing details of these in a report. Effectively this produces a type of checklist of structural components to be inspected and the data to be transferred to computerized and manual records systems of the owner authority.

A small and quickly digestible example of a primarily structural report can be found on:

www.transport.nsw.gov.au/sites/default/files/b2b/projects/TAP_Marrickville_%20Determination%20Report-Appendix%204.pdf

This is for a small platform structure on a Sydney suburban railway station. Whilst this does only appear as an appendix in a larger, general heritage report, the structural component is thus distinguishable from the rest.

The above type of inspection could be described as typically being carried out by engineers for engineers. It is important, however, to examine a very widely used type of report that has a greater range of content and contributors, aimed at a wider readership: the conservation management plan.

A suggested list of the content of a structural condition report is given in Part 5 of the ASCE publication: "Guideline for Structural Condition Assessment of Existing Buildings" (Reference 2 in Section 16).

The Conservation Management Plan (CMP)

A CMP for a heritage structure can be prepared at any time but its production is frequently prompted by the fact that something is about to happen. It would be an ideal state if all heritage items had a CMP included in their dossier but the realities of the limits of community resources mean that such a condition could never be achieved. It follows that there is usually a demand for this species of documentation at a particular time in the history of the item. As an example, development applications in the State of New South Wales must include a recent CMP if the heritage item is subject to a change of use.

The main themes within a CMP include a background description -- including a comprehensive history – of the item, a report on the current condition, the necessary repairs to be carried out and the future management/care regime proposed. A concise description of the requirements and purpose of a CMP can be found in a document from Victoria:

www.dtpli.vic.gov.au/__data/assets/pdf_file/0003/219927/CMP_Guide_1278369664770.pdf

with a suggested contents list from New South Wales:

www.environment.nsw.gov.au/resources/heritagebranch/heritage/cmpcontents2.pdf

The former document includes a checklist of contents of a CMP.

(If there is a need for more advanced study of the CMP process, it should be pointed out that, through the generosity of the estate of author James S. Kerr, his book: “The Conservation Plan” is available for free download via:

https://australia.icomos.org/publications/the-conservation-plan/

courtesy of Australia ICOMOS.)

It has already been mentioned that this type of report involves co-operation by the engineer with many other professions so it is appropriate to look at the proportion of engineering involvement. A CMP is usually commissioned from a heritage consulting organisation (or occasionally from an architect with extensive heritage experience) that has the responsibility of co-ordinating the work of the variety of other contributors. Hints on roles for engineers are given in pages from the CMP guide documents of Western Australia as shown in Section 13A.

Morpeth Bridge in New South Wales was shown in Section 7E as an example of a timber truss bridge. Its main components are three 33.6-metre trusses of the Allan type (Section 7D) so that the compression members and the bottom chords are of ironbark hardwood timber with vertical tension members that are wrought iron rods. The Bridge was due for refurbishment and upgrade under the timber bridge management strategy of Roads and Maritime Services of New South Wales. The required CMP was produced by GHD Pty Ltd, consulting engineers, in collaboration with Austral Archaeology, heritage consultants. The contents pages of the document are shown in Section 13B.

Those elements of the CMP that involve engineering input at some level have been underlined.

In the case of Part 3 that reports on the condition of the item it will be seen that all elements have been underlined. This is not surprising because the example is of a predominantly engineering subject. The layout of Part 3 will be seen to be determined by the different parts of the truss spans and deck so that there is similarity within Part 3 to a primarily engineering report as mentioned earlier.

With other parts of this particular CMP, the dominance or intrusion of engineering input and the proportion of input from other disciplines is consequently higher. One area where the engineering contribution is very strong is understandably in the parts of the CMP that deal with the future. The knowledge of maintenance procedures is featured strongly here and the contents pages of CMPs usually show these considerations in the later pages of the report.

It may be argued that the high proportion of engineering input in the Morpeth CMP was because it was mainly an engineering subject. It therefore is relevant to make a comparison with the CMP of a church in the Australian Capital Territory. This mainly brick structure was built in 1938 and indeed it is difficult to discern in the main body of the report much in the way of engineering-influenced input – even though there would be good sense in some engineering discussion as the building does have a substantial brick tower. Such matters have been relegated to Appendix 2 of the CMP. This appendix is shown in Section 13C. It cannot escape notice that damage due to settlement -- as mentioned in Section 10 – makes its appearance here: at the beginning of the second page (although there does seem to be a conflict with the first item in the Appendix).

The CMP was written by a local team of three individuals, one of whom was an engineer.

The above two examples illustrate the range of engineering input – or acknowledged range of input – into CMPs. There are CMPs that have been accepted in which there is no inclusion of a description of the condition of the item but it is difficult to see how a document that professes to include a "management" component can justify the omission of a description of its structural nature and the state that it is in, as a basis for any further discussion of its future. An example of the CMP for an internationally known bridge is given in:

https://www.scribd.com/doc/200085990/Conservation-Management-Plan-for-the-Iron-Bridge-Ironbridge-Shropshire-UK

Heritage Register Content

Engineering reports, along with reports from other professionals such as historians, archaeolgists, conservators &c, contribute to the formal submissions to the various authorities for inclusion in the respective registers and heritage inventories. The final engineering-related sector is generally much smaller than in a complete engineering report, though it is often extracted from the latter.

By inserting "Como Railway Bridge" into the "Item name" box of the New South Wales State Heritage Register search page:

www.environment.nsw.gov.au/heritageapp/heritagesearch.aspx

an SHR entry for a prominent heritage structure is displayed. The main SHR independent listings are under Section 2 and listings drawn from compilations by state government bodies (SGOV) and local government authorities (LGOV) are in Section 3. (Where a particular item is named in both sections, it is frequently found that the entry in one section contains information not included in the other – such as references from which the supporting information has been obtained.)

Throughout the main sections in the entry, engineering data is intermixed with information from other sources. This emphasises the requirement for the members of a diverse team to maintain a high level of co-operation.

A comprehensive "Guidelines for Nominations to the State Heritage Register" of New South Wales can be found on:

www.environment.nsw.gov.au/resources/heritagebranch/heritage/NominationsGuideline2006.pdf

Part C "Description" under Step2 ("Completing the Form") is likely to be the main sector of the application for engineering information which is interwoven with other contributions. If there is an omission in the instructions here, it is that there is no prompting for the supply of a few main dimensions in order to provide some concept of how big the item is.

Having stressed the important points in the description, it is probable that engineering considerations will find their way into the Part B "Significance" section. It also assists with the quality of the submission if relevant engineering documents and reports are included in sub-section 13 as many entries show evidence of having been submitted without the engineering expertise that would have been appropriate.

- Current heritage listings of the place.
- Acknowledgements of people and funding as appropriate.
- An outline of the methodology employed by the consultant in the preparation of the report.
- Study team and management structure for the project.

2. EVIDENCE

If the place is on the State Register of Heritage Places and has a substantial Heritage Council Assessment Documentation, this document should be used as a basis for this section of the CMP. Additional information should be added as necessary to bring the information up-to-date, respond to any unresolved issues and/or support the development of detailed conservation policies. Where the Assessment Documentation is used, the source document and the original authors should be clearly acknowledged.

In the preparation of documentary and physical evidence, consideration should be given to the items listed in Section 3.2 of the *Guidelines to the Burra Charter; Cultural Significance.*

Note: Technical expertise should be used appropriate to the condition and nature of the place. For example, experts may include a landscape architect, historical archaeologist, or specialist engineer. The findings of these experts should be integrated in the relevant section(s) of the report to allow a comprehensive understanding of the place. Detailed reports should also be included in full as an appendix.

2.1 Documentary Evidence

This section is to be prepared by an historian or suitably qualified archaeologist. The documentary evidence is to provide an understanding of the following:

- Pre-colonial occupation (where relevant).
- Historical context - for example, its place within the development of a locality/region or its association with the development of a particular industry.
- A history of the place from its past site use, establishment and construction up to present day, including its role and associations.
- A summarised chronology of major events.

Where an unsuccessful attempt has been made to locate important information, this should be noted in the documentary evidence (types of sources and depositories/locations searched).

Potential oral sources of information may also be investigated and, where possible, archival plans and photographs are to be provided to document the development of the place. Historic plans should be included to provide an understanding of the evolution of the place.

2.2 Physical Evidence

This section is to be prepared by an architect, historical archaeologist, engineer and/or landscape architect or other person with expertise as appropriate to the nature and condition of the place. There should be a clear statement about the methodology of the physical investigations undertaken and any limitations during the investigations. Issues or areas of concern should be clearly identified. Structural engineering reports may be commissioned as appropriate to provide understanding of the structural integrity of the place and to assist in developing policies arising from the physical condition of the place.

The physical evidence is to provide an understanding of the following:

- The context of the building(s)/features within the landscape/setting.
- A description of the current function of the place and building(s).
- A description of the surviving fabric (including any artefacts/movable heritage).
- Assessment of potential for archaeological remains
- A general assessment of the physical condition of the place. Structural engineering or other specialist reports may need to be commissioned as appropriate.

The use to which a place was originally built is always the preferred ongoing use, but if this is not viable then a compatible use is preferred if the following principles are applied:

- The integrity of the place is maintained, including retention of significant interior and exterior spaces
- The adaptations and/or additions are easily reversible without causing damage to the significant fabric
- The opportunity for interpretation of the place and archaeological features or materials that may be uncovered
- The development provides the opportunity to conserve fabric described in other sections of the CMP

7.7 Policies Relating to Renewable Energy Systems

Issues relating to installation of renewable energy systems should be considered. In particular, possible future requirements relating to modern technology and sustainability, and the areas and/or zones where this may be accommodated without undue impact on heritage values.

The principles set out in the State Heritage Office's publication *Renewable Energy Systems in State Registered Places* should be applied.

7.8 Policies Related to Interpretation

It is considered desirable to interpret the history and significance of a heritage place for visitors and/or users. This policy section should discuss broad principles or themes for appropriate methods and expertise for interpretation, use of interpretive material, and/or future recommendations. If an Interpretation Plan is to be recommended, then specific issues to be addressed in the Interpretation Plan are to be stated and justified.

7.9 Other

Identify any other areas not addressed in the above policy sections and develop specific policies on these issues.

8. POLICY IMPLEMENTATION

Arising from the policies in Section 7, a conservation works schedule and maintenance works schedule should be collated to ensure that implementation of policies are undertaken within appropriate timeframes.

8.1 Recommended Conservation Works Schedule

Works that are required to address issues identified in the previous sections should be outlined in a schedule that establishes the sequence of activities to be undertaken in response to priorities and resources.

Works should be categorised into 'urgent works' (to be actioned within 12 months); 'short-term works' (within two years); 'medium-term works' (within five years); 'long-term works' (within 10 years); and desirable works.

8.2 Recommended Maintenance Works Schedule

Other than conservation works, the CMP should also address ongoing maintenance works for the place. A schedule of maintenance works should be drawn up to ensure that upkeep of the place is programmed.

9. APPENDICES

Any information that may be critical to an understanding of the Conservation Management Plan report or its preparation should be included as an appendix. For documents available online, a web address will be sufficient. Appendices could include such things as:

- Documentary and physical evidence. For example, title deeds, reports and plans, building schedules etc. Documents shall include scale, orientation, date and designation where applicable
- *Guidelines to The Burra Charter: Cultural Significance' and/or 'Guidelines to The Burra Charter: Conservation Policy*
- The State Heritage Office's *Criteria of Cultural Heritage Significance for Assessment of Places for Entry Into the Register of Heritage Places*; and
- Details of heritage listings/registrations

Morpeth Bridge over the Hunter River

Conservation Management Plan

Contents

APPENDIX 2

CONDITION REPORT 2015

The following table was generated by current and former members of the Parish Council and most of the items checked on site on 18 March 2015. Some issues in the table below have been addressed but have been retained for future reference. The priority level is based on ensuring safety and comfort of users and arresting decay of building fabric.

Priority legend:

Urgent	implement the recommendation immediately
High	implement within 12 months ie in 2016
Medium	implement within 3 years ie before 2018
Low	implement in approximately 5 years ie circa 2020
On-going	tasks should be checked as part of regular maintenance

Item	**Issue**	**Recommendation**	**Prty**
FOUNDATIONS			
Foundation movement or differential settlement	No obvious evidence of foundation movement or settlement.	Monitor	L
Adjacent vegetation	Small pine, privet and ground creepers growing at base of Eastern (Sanctuary) wall.	Remove plants	M
	Wildings including an Oak on north elevation	remove	H
	Rose on north elevation	Prune and consider fixed trellis	H
Soil level around building	Surrounding ponding issues now addressed with new drainage works. Generally keep all soil level below ventilation bricks.	Remove soil level where it is above base of vents then monitor.	on-going
	SW Corner of Vestry – soil and vegetation has built up above floor level	Remove soil and vegetation to below floor or vent level	H
Site drainage around building	Grated drain at base of ramp to South door is clogged.	Clean clogged drain and generally keep spoon	on-going

		drain on the south side of church clear of debris.	
WALLS			
Settlement cracks	There are numerous settlement cracks around the church most of which are relatively minor. Those warranting attention include the cracks in the brick arches that link the aisle columns to the external wall. Preliminary steps are being taken toward their analysis and monitoring in 2015, The crack above the west entry door is in masonry dating to 2001. This is relatively recent and hence should also be actively monitored. Cracks were also noted in the north door side walls of the steps and over the north porch internal door inside & outside At the baptistery –there are cracks in the internal arch and adjacent the external window Inspections carried out in 1939/1956/2000, continue to monitor all cracking	Implement structural assessment of cracking in heads of brickwork arches in side aisles and nave. Take engineering advice and monitor or repair cracks as per specialist advice.	H
Leaning walls	Visual check – All walls appear vertical and not considered to be of concern.	-	-
Condition of mortar and pointing	Visual check indicates some mortar loss and future need for pointing at east end, at the base of the tower and around north entrance porch. Currently not a significant problem but needs continuous monitoring and future repointing.	Repoint as appropriate	L
Penetrating damp	Issues of penetrating damp have been addressed, mainly by 2014 roof works. Damp appears to be receding throughout the Church building.	monitor	-
Brick sills heads, parapets, gable ends and pilasters	Internal head of north door has cracked.	monitor	-
Algae and moss on walls	Moss is evident on gable and parapet wall of church building Baptistery South wall	Remove using algaecide and scraping. Do not use high pressure spray as it could damage mortar.	L

14. LISTS AND REGISTERS

IS THE STRUCTURE PROTECTED OR ON A LIST?

Many items of heritage value have protection by law from demolition or alteration. A step in this process is formal inclusion in some listing that operates under the authority of a government or government-related body. There are also lists that have been created by independent organisations which, although they do not directly convey the any direct legal protection, do carry weight in most assessment processes when a development application is being assessed. It is recognised that there are many items of genuine heritage significance that do not yet appear in lists.

With regard to lists of government origin, in Australia these originate in three levels: Commonwealth (national), state and local government authorities (LGAs). Apart from items of International heritage value, the Commonwealth list of items of national significance currently numbers 106 although most engineers are unlikely to encounter projects that have impact on items of such eminence. The Commonwealth also has another list of about four hundred items of heritage value that it owns.

https://www.environment.gov.au/heritage/places/commonwealth-heritage-list

Register of the National Estate

For over thirty years, the Commonwealth also ran the very large Register of the National Estate but, due to a change in policy, this valuable source of information has not been added to for the last few years. It is, however, still accessible on the web and a search in this is recommended as some of the information entries in the RNE are quite large.

State Heritage Register – New South Wales

On the state scene New South Wales, for example, has its State Heritage Register which is a product of the Heritage Act. In the event of a proposed development that could affect an item on the SHR, a very formal process of application and review under the various requirements of the Heritage Act must be undertaken in order to entertain any possibility of the development taking place in full or in part.

http://www.environment.nsw.gov.au/Heritage/listings/stateheritageregister.htm

Information for the SHR comes from different sources as will be seen from the following.

Example 1.

When looking for a particular item, it is good practice to widen the search over an area covering the location. This is because different persons and authorities putting information into the SHR have been found to use different addresses or geographical locations for the same item or even slightly different names.

http://www.environment.nsw.gov.au/heritageapp/heritagesearch.aspx

As an example, the rural LGA of Guyra has been put into the LGA box of the SHR search form with the result as shown in Section 14A.

It will be seen that the SHR is comprised of three sections. The first of these contains items of indigenous significance. The second section could be described as a general section to which items are submitted and added on a one-by-one basis. The third section contains items in the registers or lists that are required by the Heritage Act from government organisations (denoted by "SGOV" in the last column) and the heritage items in the lists that form part of the local environment plans (LEPs) of LGAs ("LGOV").

It is often found that a particular item has an entry in both the second and the third sections of the SHR indicating local and state significance. Occasionally an item appears as three entries as in the case of "Ben Lomond Railway Station", "Ben Lomond Railway Precinct" and "Railway Station – Ben Lomond" in the Guyra search. (This example also gives warning, as previously noted, that it is better to cast the geographical net wider because of name variations.) If an item appears more than once, all names in the original search should be clicked on if the full entries are sought because it must be remember that the different entries have been authored by different groups and frequently it is found that the information is also different.

The SHR provides a very high degree of protection for items so that there is a very formal process to be undertaken when a project will result in some impact. Section 60 of the Heritage Act does allow for applications for such projects:

http://www.environment.nsw.gov.au/Heritage/development/section60.htm

There is then notification to the public and display before the Heritage Council decides whether to approve the proposal or not.

The National Trust

The bodies bearing the name of National Trust are primarily organized on a state basis, such as The National Trust of Australia (NSW). This organization started in 1945 and, from the first, commenced a listing process of heritage items together with supporting data. The result has been a wealth of information available to the public in relation to heritage items, especially where there is likely to be impact or threat. This was particularly useful in the period before the Heritage Act started to be effective from 1977. Listing by the National Trust in itself provides no direct protection by law but the large collection of data and the long period that the NT has been in operation are factors that always are the components of appraisal of projects by the Heritage Council and other assessment bodies.

The register itself is not currently online and enquires are made for specific projects: https://www.nationaltrust.org.au/services/trust-register-nsw/ or:

advocacy@nationaltrust.com.au

Section 14B is a traditional National Trust (NSW) register entry for Crago Mill, Newtown, which is Example 2 in Section 6 and is illustrated in Section 6B.

Aboriginal Heritage Information Management System

Many construction projects, particularly in rural areas, have some contact or potential impact with items to be found within AHIMS. Compared with other types of listing, there is an element of difficulty in that there is a need to provide protection by a level of non-disclosure of location, for example, in order to deter vandalism in what are often remote places. The desirability of some secrecy is also often related to cultural considerations. Information from AHIMS is therefore on a direct enquiry basis and may be obtained via:

www.environment.nsw.gov.au/licences/WhatInformationCanYouObtainFromAHIMS.htm or www.environment.nsw.gov.au/awssapp/login.aspx

An Aboriginal Heritage Impact Permit must be sought and the procedures must follow the Due Diligence Code of Practice applicable in such areas.

Engineers Australia

Since 1984, Engineering Heritage Australia has compiled a listing of items of heritage significance and these have been provided with explanatory plaques or information and interpretation panels. The documentation supporting the submissions for most of these is usually more extensive than for the average listing.

A search for "Engineering Heritage Recognition Program" is the most direct means of getting access to the entries.

Local Environment Plans

The LEPs of local government authorities have been referred to above in connection with the State Heritage Register. An additional valuable component of these is that heritage items are plotted on the map(s) that accompany the formal presentation of the LEPs on the various council websites. This type of display is particularly useful in the case of projects that involve the use of large areas.

Australian Institute of Architects

The AIA has maintained a "Register of Significant Buildings" since 1944 and a computer search using this title will produce a pdf format. The list is arranged in order of local government authority.

Search for NSW heritage

Return to search page where you can refine/broaden your search.

SEARCH: LOCAL GOVERNMENT AREA -- GUYRA

Statutory listed items

Information and items listed in the State Heritage Inventory come from a number of sources. This means that there may be several entries for the same heritage item in the database. For clarity, the search results have been divided into three sections.

- **Section 1** - contains Aboriginal Places declared by the **Minister for the Environment** under the National Parks and Wildlife Act. This information is provided by the Heritage Division.
- **Section 2** - contains heritage items listed by the **Heritage Council of NSW** under the NSW Heritage Act. This includes listing on the State Heritage Register, an Interim Heritage Order or protected under section 136 of the NSW Heritage Act. This information is provided by the Heritage Division.
- **Section 3** - contains items listed by **local councils** on Local Environmental Plans under the Environmental Planning and Assessment Act, 1979 and **State government agencies** under s.170 of the Heritage Act. This information is provided by local councils and State government agencies.

Section 1. Aboriginal Places listed under the National Parks and Wildlife Act.

Your search returned 1 record.

Aboriginal place name	Local government area	Local Aboriginal Land Council	Latitude	Longitude	Gazettal date and page numbers	Comments
Devil's Chimney	Guyra	Armidale	-30.167745698	152.198077711	08/08/1980 p. 4068	

Section 2. Items listed under the NSW Heritage Act.

Your search returned 5 records.

Item name	Address	Suburb	LGA	SHR
Ben Lomond Railway Station	Main Northern railway	Ben Lomond	Guyra	01083

Black Mountain Railway Station	Main Northern railway	Black Mountain	Guyra	01087
Guyra Railway Station group	Main Northern railway	Guyra	Guyra	01163
High Conservation Value Old Growth Forest	15 Local Government Areas	Upper North East NSW	Multiple LGAs	01487
Wing Hing Long & Co. Store	10 Ruby Street	Tingha	Guyra	01307

Section 3. Items listed by Local Government and State Agencies.

Your search returned 11 records.

Item name	Address	Suburb	LGA	Information source
Archaeological- Watermill remains	2km east of New England Highway, Streeter's Road	Ben Lomomd	Guyra	LGOV
Ben Lomond Railway Precinct	Ben Lomond Road	Ben Lomond	Guyra	SGOV
Guyra Railway Precinct		Guyra	Guyra	SGOV
Office - Former W.A. Robert's Drapery	100 Bradley Street	Guyra	Guyra	LGOV
Railway Station - Ben Lomond	Main Northern Railway	Ben Lomond	Guyra	LGOV
Railway Station - Ben Lomond Railway Station And Yard Group	Main Northern Line	Ben Lomond	Guyra	LGOV
Railway Station - Black Mountain	Main Northern line	Black Mountain	Guyra	LGOV
Railway Station - Black Mountain Railway Station Group	Main Northern Railway Line	Black Mountain	Guyra	LGOV
Station - Ollera Station including Cottage, Shearing Shed and Chapel	196 Tenterden Road	Guyra	Guyra	LGOV
Tingha Official Residence 1	24 Ruby Street	Tingha	Guyra	SGOV
Tingha Police Station	Opal Street, Corner Ohio Street	Tingha	Guyra	SGOV

There was a total of 17 records matching your search criteria.

Key:
LGA = Local Government Area
GAZ= NSW Government Gazette (statutory listings prior to 1997), HGA = Heritage Grant Application, HS = Heritage Study, LGOV = Local Government, SGOV = State Government Agency.

Note: While the Heritage Division seeks to keep the Inventory up to date, it is reliant on State agencies and local councils to provide their data. Always check with the relevant State agency or local council for the most up-to-date information.

NATIONAL TRUST (NSW) REGISTER ENTRY

S 7236

NEWTOWN
(Town or District)

Post Code 2042 Marrickville Council
Local Govt Area

Author of Proposal: B Little, S Ungar

Date of Proposal: August 1981, revised Nov 1984

Suggested Listing Category: CLASSIFIED

Committee (Trust Use): IAC SEE OVER

Council (Trust Use): APPROVED CLASSIFIED 24/9/84

CRAGO FLOUR MILL
(Name or Identification of Listing)

Bibliography

between Gladstone St & the main suburban railway line at Newtown
(Address or Location)

Owner and Address
Allied Mills Industries
2 Smith Street
SUMMER HILL NSW 2130

Description — Briefly cover the points on the following check list where they are relevant and within your knowledge.

Style / Construction / Use / Architect/s / Builder/s / Date of Construction / Present Condition / History / Owners / Boundaries of proposed listing

This large purpose-built, brick, flour mill, with three storeys and basement, with space for a roller floor, wheat cleaning and wheat store, was built by J Dunkley for Francis Crago, to a design by Nixon and Allen, in 1896. The building was rebuilt to the same design after a disastrous fire in 1900. The Crago family had operated a mill at Bathurst, but moved to this site to take advantage of the proximity to the Sydney market. The rail siding, originally for receiving bagged wheat from the country, converted easily to receiving bulk wheat in the 1930s, and the concrete silos were erected in 1936.

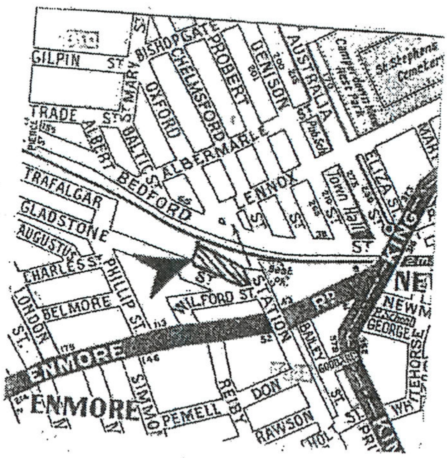
The mill was originally steam powered, now converted to electricity, and the machinery and equipment by Henry Simon (Aust). The building is surrounded by the many extensions that have been built, mostly in corrugated iron. The main milling tower, of three storeys, single gabled with brick pilasters forming three recessed arches across the frontage, with a classical pediment, is flanked on one side by a two storey storage building, and on the other by a single storey engine house. A central inscription reads "CRAGO FLOUR MILL - ERECTED 1896."

(See over) .../2

Reasons for listing

A fine example of a large city mill, built during a period of rationalisation of the milling industry, with all the advantages that have made its continuing operation viable. Its location, close to the city and major arteries, with rail access and a private siding, represents a thoughtful consideration of the economic forces then affecting the industry, and the mill is typical of this roller milling technology in its developed form, before the economics of scale produced the large, high-technology complexes that exist today.

Sketch plan and photos
Attach additional photos if any.



DESCRIPTION (CONTINUED)

The mill ceased operations in April 1984. At present the equipment remains in working order, in situ, but the operations have become too expensive at this site. Extant equipment includes Simons and Robinsons milling machinery, timber shifts and an early finished grain drier. Other notable features are two large concrete silos and tramlines set in cobblestones, to the north of the site, which are reputed to be the oldest surviving in Sydney. In 1908 the name of the mill was changed to the FEDERAL FLOUR MILL, which made "Diamond Flour".

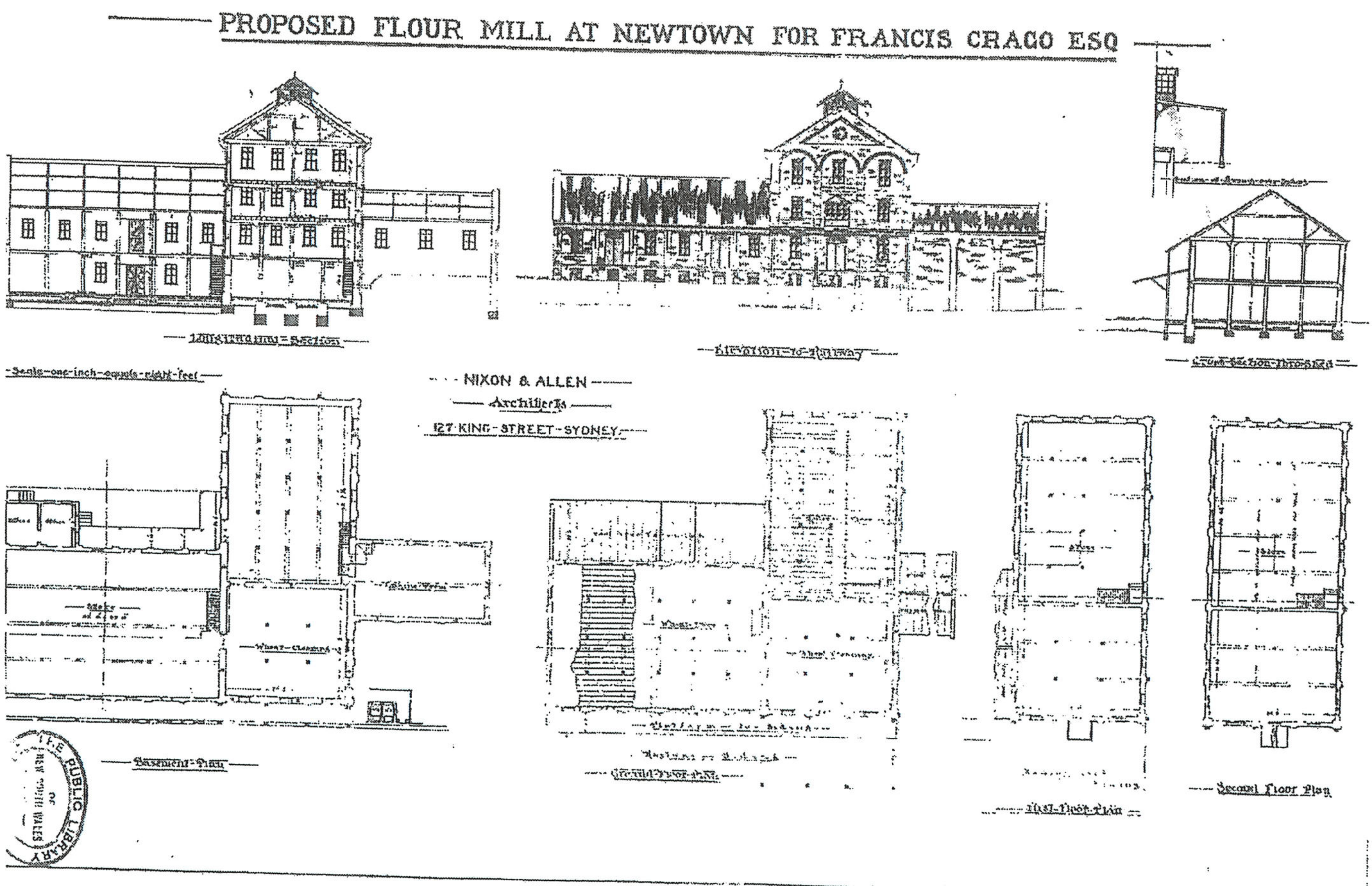
CURTILAGE:

Site to be defined by property boundary (roughly Railway line, Gladstone Street, Wilford Street, Station Street)

Owner notified 19/10/84 Form letter IAC/2a

COMMITTEE REFERENCES:

IAC/137:	15/ 2/84:	deferred
IAC/138:	21/ 3/84:	recommended CLASSIFY
Council:	24/ 9/84:	approved "



Mill at Newtown.

Nixon & Allen, Architects, King Street, Sydney.

15. THE BURRA CHARTER

HOW FAR SHOULD THE WORK GO?

An engineer dealing with the restoration and/or reuse of an existing structure containing a heritage element is faced with a task of optimisation greater than that for designing a new structure. If too much work is done, there is the danger that the heritage value is reduced or possibly destroyed. A complication is that there are often different opinions as to where the boundary between these apparently opposing factors should be placed.

The International Council on Monuments and Sites (ICOMOS) in 1965 endorsed a series of guidelines proposed at a related technical conference held in Venice the previous year. Known as the Venice Charter, it provided pointers to the resolution of the dilemma referred to above.

The local equivalent of the above international organisation, Australia ICOMOS, reviewed the Venice Charter over the following years and decided to make very substantial revisions based on local conditions and requirements, resulting in a much more comprehensive document. This product was approved at the annual meeting of Australia ICOMOS in the town of Burra, South Australia, in 1977 and has been revised twice since.

All engineers dealing with heritage matters will refer to the Burra Charter as a working reference. The document is to be found as Section 15A of these notes. Also downloadable as a primary reference is: "Engineering Heritage and Conservation Guidelines" of Engineers Australia.

On opening up the Charter, it presents a slightly forbidding appearance in that it at first looks similar to an act of parliament in its structure. But this is a necessary feature for the logical presentation of ideas.

It is nonetheless useful in the present context to start in the middle. Articles 16 to 22 inclusive in the Charter list possible levels of action. It will be noted that four of the terms used here: maintenance, preservation, restoration and reconstruction constitute an ever-increasing range of intervention that will be the subject of discussion between engineers, architects heritage experts and conservators relevant to the project. Reference needs to be made to the definitions in Article 1 of the Charter so that the correct principles of conservation, as explained from Article 2 onwards, are applied.

The Burra Charter, in its various editions, has been refined to become a widely used yardstick by authorities in the assessment of development applications in checking that a proposed project relates to the guidelines of the Charter.

http://www.teachingheritage.nsw.edu.au/section01/burra.php

Overseas approaches:

https://www.nps.gov/tps/standards/rehabilitation/rehab/guide.htm http://site.cibworld.nl/dl/publications/pub335.pdf

Search: "Illustrated Burra Charter"

THE BURRA CHARTER

The Australia ICOMOS Charter for Places of Cultural Significance

2013

AUSTRALIA ICOMOS
International Council on Monuments and Sites

Australia ICOMOS Incorporated
International Council on Monuments and Sites

ICOMOS

ICOMOS (International Council on Monuments and Sites) is a non-governmental professional organisation formed in 1965, with headquarters in Paris. ICOMOS is primarily concerned with the philosophy, terminology, methodology and techniques of cultural heritage conservation. It is closely linked to UNESCO, particularly in its role under the World Heritage Convention 1972 as UNESCO's principal adviser on cultural matters related to World Heritage. The 11,000 members of ICOMOS include architects, town planners, demographers, archaeologists, geographers, historians, conservators, anthropologists, scientists, engineers and heritage administrators. Members in the 103 countries belonging to ICOMOS are formed into National Committees and participate in a range of conservation projects, research work, intercultural exchanges and cooperative activities. ICOMOS also has 27 International Scientific Committees that focus on particular aspects of the conservation field. ICOMOS members meet triennially in a General Assembly.

Australia ICOMOS

The Australian National Committee of ICOMOS (Australia ICOMOS) was formed in 1976. It elects an Executive Committee of 15 members, which is responsible for carrying out national programs and participating in decisions of ICOMOS as an international organisation. It provides expert advice as required by ICOMOS, especially in its relationship with the World Heritage Committee. Australia ICOMOS acts as a national and international link between public authorities, institutions and individuals involved in the study and conservation of all places of cultural significance. Australia ICOMOS members participate in a range of conservation activities including site visits, training, conferences and meetings.

Revision of the Burra Charter

The Burra Charter was first adopted in 1979 at the historic South Australian mining town of Burra. Minor revisions were made in 1981 and 1988, with more substantial changes in 1999.

Following a review this version was adopted by Australia ICOMOS in October 2013.

The review process included replacement of the 1988 Guidelines to the Burra Charter with Practice Notes which are available at: australia.icomos.org

Australia ICOMOS documents are periodically reviewed and we welcome any comments.

Citing the Burra Charter

The full reference is *The Burra Charter: The Australia ICOMOS Charter for Places of Cultural Significance, 2013*. Initial textual references should be in the form of the *Australia ICOMOS Burra Charter, 2013* and later references in the short form (*Burra Charter*).

Cover photograph by Ian Stapleton.

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The Burra Charter

(The Australia ICOMOS Charter for Places of Cultural Significance, 2013)

Preamble

Considering the International Charter for the Conservation and Restoration of Monuments and Sites (Venice 1964), and the Resolutions of the 5th General Assembly of the International Council on Monuments and Sites (ICOMOS) (Moscow 1978), the Burra Charter was adopted by Australia ICOMOS (the Australian National Committee of ICOMOS) on 19 August 1979 at Burra, South Australia. Revisions were adopted on 23 February 1981, 23 April 1988, 26 November 1999 and 31 October 2013.

The Burra Charter provides guidance for the conservation and management of places of cultural significance (cultural heritage places), and is based on the knowledge and experience of Australia ICOMOS members.

Conservation is an integral part of the management of places of cultural significance and is an ongoing responsibility.

Who is the Charter for?

The Charter sets a standard of practice for those who provide advice, make decisions about, or undertake works to places of cultural significance, including owners, managers and custodians.

Using the Charter

The Charter should be read as a whole. Many articles are interdependent.

The Charter consists of:

- Definitions — Article 1
- Conservation Principles — Articles 2–13
- Conservation Processes — Articles 14–25
- Conservation Practices — Articles 26–34
- The Burra Charter Process flow chart.

The key concepts are included in the Conservation Principles section and these are further developed in the Conservation Processes and Conservation Practice sections. The flow chart explains the Burra Charter Process (Article 6) and is an integral part of the Charter. Explanatory Notes also form part of the Charter.

The Charter is self-contained, but aspects of its use and application are further explained, in a series of Australia ICOMOS Practice Notes, in *The Illustrated Burra Charter*, and in other guiding documents available from the Australia ICOMOS web site: australia.icomos.org.

What places does the Charter apply to?

The Charter can be applied to all types of places of cultural significance including natural, Indigenous and historic places with cultural values.

The standards of other organisations may also be relevant. These include the *Australian Natural Heritage Charter*, *Ask First: a guide to respecting Indigenous heritage places and values* and *Significance 2.0: a guide to assessing the significance of collections*.

National and international charters and other doctrine may be relevant. See australia.icomos.org.

Why conserve?

Places of cultural significance enrich people's lives, often providing a deep and inspirational sense of connection to community and landscape, to the past and to lived experiences. They are historical records, that are important expressions of Australian identity and experience. Places of cultural significance reflect the diversity of our communities, telling us about who we are and the past that has formed us and the Australian landscape. They are irreplaceable and precious.

These places of cultural significance must be conserved for present and future generations in accordance with the principle of inter-generational equity.

The Burra Charter advocates a cautious approach to change: do as much as necessary to care for the place and to make it useable, but otherwise change it as little as possible so that its cultural significance is retained.

Articles

Article 1. Definitions

For the purposes of this Charter:

1.1 *Place* means a geographically defined area. It may include elements, objects, spaces and views. Place may have tangible and intangible dimensions.

> Place has a broad scope and includes natural and cultural features. Place can be large or small: for example, a memorial, a tree, an individual building or group of buildings, the location of an historical event, an urban area or town, a cultural landscape, a garden, an industrial plant, a shipwreck, a site with in situ remains, a stone arrangement, a road or travel route, a community meeting place, a site with spiritual or religious connections.

1.2 *Cultural significance* means aesthetic, historic, scientific, social or spiritual value for past, present or future generations.

Cultural significance is embodied in the *place* itself, its *fabric*, *setting*, *use*, *associations*, *meanings*, records, *related places* and *related objects*.

Places may have a range of values for different individuals or groups.

> The term cultural significance is synonymous with cultural heritage significance and cultural heritage value.
>
> Cultural significance may change over time and with use.
>
> Understanding of cultural significance may change as a result of new information.

1.3 *Fabric* means all the physical material of the *place* including elements, fixtures, contents and objects.

> Fabric includes building interiors and sub-surface remains, as well as excavated material.
>
> Natural elements of a place may also constitute fabric. For example the rocks that signify a Dreaming place.
>
> Fabric may define spaces and views and these may be part of the significance of the place.

1.4 *Conservation* means all the processes of looking after a *place* so as to retain its *cultural significance*.

> See also Article 14.

1.5 *Maintenance* means the continuous protective care of a *place*, and its *setting*.

Maintenance is to be distinguished from repair which involves *restoration* or *reconstruction*.

> Examples of protective care include:
>
> - maintenance — regular inspection and cleaning of a place, e.g. mowing and pruning in a garden;
> - repair involving restoration — returning dislodged or relocated fabric to its original location e.g. loose roof gutters on a building or displaced rocks in a stone bora ring;
> - repair involving reconstruction — replacing decayed fabric with new fabric

1.6 *Preservation* means maintaining a *place* in its existing state and retarding deterioration.

> It is recognised that all places and their elements change over time at varying rates.

1.7 *Restoration* means returning a *place* to a known earlier state by removing accretions or by reassembling existing elements without the introduction of new material.

1.8 *Reconstruction* means returning a *place* to a known earlier state and is distinguished from *restoration* by the introduction of new material.

> New material may include recycled material salvaged from other places. This should not be to the detriment of any place of cultural significance.

1.9 *Adaptation* means changing a *place* to suit the existing *use* or a proposed use.

1.10 *Use* means the functions of a *place*, including the activities and traditional and customary practices that may occur at the place or are dependent on the place.

> Use includes for example cultural practices commonly associated with Indigenous peoples such as ceremonies, hunting and fishing, and fulfillment of traditional obligations. Exercising a right of access may be a use.

Explanatory Notes

Articles

1.11 *Compatible use* means a *use* which respects the *cultural significance* of a *place*. Such a use involves no, or minimal, impact on cultural significance.

1.12 *Setting* means the immediate and extended environment of a *place* that is part of or contributes to its *cultural significance* and distinctive character.

1.13 *Related place* means a *place* that contributes to the *cultural significance* of another place.

1.14 *Related object* means an object that contributes to the *cultural significance* of a *place* but is not at the place.

1.15 *Associations* mean the connections that exist between people and a *place*.

1.16 *Meanings* denote what a *place* signifies, indicates, evokes or expresses to people.

1.17 *Interpretation* means all the ways of presenting the *cultural significance* of a *place*.

Conservation Principles

Article 2. Conservation and management

2.1 *Places* of *cultural significance* should be conserved.

2.2 The aim of *conservation* is to retain the *cultural significance* of a *place*.

2.3 *Conservation* is an integral part of good management of *places* of *cultural significance*.

2.4 *Places* of *cultural significance* should be safeguarded and not put at risk or left in a vulnerable state.

Article 3. Cautious approach

3.1 *Conservation* is based on a respect for the existing *fabric*, *use*, *associations* and *meanings*. It requires a cautious approach of changing as much as necessary but as little as possible.

3.2 Changes to a *place* should not distort the physical or other evidence it provides, nor be based on conjecture.

Article 4. Knowledge, skills and techniques

4.1 *Conservation* should make use of all the knowledge, skills and disciplines which can contribute to the study and care of the *place*.

Explanatory Notes

Setting may include: structures, spaces, land, water and sky; the visual setting including views to and from the place, and along a cultural route; and other sensory aspects of the setting such as smells and sounds. Setting may also include historical and contemporary relationships, such as use and activities, social and spiritual practices, and relationships with other places, both tangible and intangible.

Objects at a place are encompassed by the definition of place, and may or may not contribute to its cultural significance.

Associations may include social or spiritual values and cultural responsibilities for a place.

Meanings generally relate to intangible dimensions such as symbolic qualities and memories.

Interpretation may be a combination of the treatment of the fabric (e.g. maintenance, restoration, reconstruction); the use of and activities at the place; and the use of introduced explanatory material.

The traces of additions, alterations and earlier treatments to the fabric of a place are evidence of its history and uses which may be part of its significance. Conservation action should assist and not impede their understanding.

Articles

Explanatory Notes

4.2 Traditional techniques and materials are preferred for the *conservation* of significant *fabric*. In some circumstances modern techniques and materials which offer substantial conservation benefits may be appropriate.

The use of modern materials and techniques must be supported by firm scientific evidence or by a body of experience.

Article 5. Values

5.1 *Conservation* of a *place* should identify and take into consideration all aspects of cultural and natural significance without unwarranted emphasis on any one value at the expense of others.

Conservation of places with natural significance is explained in the Australian Natural Heritage Charter. This Charter defines natural significance to mean the importance of ecosystems, biodiversity and geodiversity for their existence value or for present or future generations, in terms of their scientific, social, aesthetic and life-support value.

In some cultures, natural and cultural values are indivisible.

5.2 Relative degrees of *cultural significance* may lead to different *conservation* actions at a place.

A cautious approach is needed, as understanding of cultural significance may change. This article should not be used to justify actions which do not retain cultural significance.

Article 6. Burra Charter Process

6.1 The *cultural significance* of a *place* and other issues affecting its future are best understood by a sequence of collecting and analysing information before making decisions. Understanding cultural significance comes first, then development of policy and finally management of the place in accordance with the policy. This is the Burra Charter Process.

The Burra Charter Process, or sequence of investigations, decisions and actions, is illustrated below and in more detail in the accompanying flow chart which forms part of the Charter.

Understand Significance

↓

Develop Policy

↓

Manage in Accordance with Policy

6.2 Policy for managing a *place* must be based on an understanding of its *cultural significance*.

6.3 Policy development should also include consideration of other factors affecting the future of a *place* such as the owner's needs, resources, external constraints and its physical condition.

6.4 In developing an effective policy, different ways to retain *cultural significance* and address other factors may need to be explored.

Options considered may include a range of uses and changes (e.g. adaptation) to a place.

6.5 Changes in circumstances, or new information or perspectives, may require reiteration of part or all of the Burra Charter Process.

Article 7. Use

7.1 Where the *use* of a *place* is of *cultural significance* it should be retained.

7.2 A *place* should have a *compatible use*.

The policy should identify a use or combination of uses or constraints on uses that retain the cultural significance of the place. New use of a place should involve minimal change to significant fabric and use; should respect associations and meanings; and where appropriate should provide for continuation of activities and practices which contribute to the cultural significance of the place.

Articles

Explanatory Notes

Article 8. Setting

Conservation requires the retention of an appropriate *setting*. This includes retention of the visual and sensory setting, as well as the retention of spiritual and other cultural relationships that contribute to the *cultural significance* of the *place*.

New construction, demolition, intrusions or other changes which would adversely affect the setting or relationships are not appropriate.

Setting is explained in Article 1.12.

Article 9. Location

9.1 The physical location of a *place* is part of its *cultural significance*. A building, work or other element of a place should remain in its historical location. Relocation is generally unacceptable unless this is the sole practical means of ensuring its survival.

9.2 Some buildings, works or other elements of *places* were designed to be readily removable or already have a history of relocation. Provided such buildings, works or other elements do not have significant links with their present location, removal may be appropriate.

9.3 If any building, work or other element is moved, it should be moved to an appropriate location and given an appropriate *use*. Such action should not be to the detriment of any *place* of *cultural significance*.

Article 10. Contents

Contents, fixtures and objects which contribute to the *cultural significance* of a *place* should be retained at that place. Their removal is unacceptable unless it is: the sole means of ensuring their security and *preservation*; on a temporary basis for treatment or exhibition; for cultural reasons; for health and safety; or to protect the place. Such contents, fixtures and objects should be returned where circumstances permit and it is culturally appropriate.

For example, the repatriation (returning) of an object or element to a place may be important to Indigenous cultures, and may be essential to the retention of its cultural significance.

Article 28 covers the circumstances where significant fabric might be disturbed, for example, during archaeological excavation.

Article 33 deals with significant fabric that has been removed from a place.

Article 11. Related places and objects

The contribution which *related places* and *related objects* make to the *cultural significance* of the *place* should be retained.

Article 12. Participation

Conservation, interpretation and management of a *place* should provide for the participation of people for whom the place has significant *associations* and *meanings*, or who have social, spiritual or other cultural responsibilities for the place.

Article 13. Co-existence of cultural values

Co-existence of cultural values should always be recognised, respected and encouraged. This is especially important in cases where they conflict.

For some places, conflicting cultural values may affect policy development and management decisions. In Article 13, the term cultural values refers to those beliefs which are important to a cultural group, including but not limited to political, religious, spiritual and moral beliefs. This is broader than values associated with cultural significance.

Conservation Processes

Article 14. Conservation processes

Conservation may, according to circumstance, include the processes of: retention or reintroduction of a *use*; retention of *associations* and *meanings*; *maintenance, preservation*, *restoration*, *reconstruction*, *adaptation* and *interpretation*; and will commonly include a combination of more than one of these. Conservation may also include retention of the contribution that *related places* and *related objects* make to the *cultural significance* of a *place*.

Conservation normally seeks to slow deterioration unless the significance of the place dictates otherwise. There may be circumstances where no action is required to achieve conservation.

Article 15. Change

15.1 Change may be necessary to retain *cultural significance*, but is undesirable where it reduces cultural significance. The amount of change to a *place* and its *use* should be guided by the *cultural significance* of the place and its appropriate *interpretation*.

When change is being considered, including for a temporary use, a range of options should be explored to seek the option which minimises any reduction to its cultural significance.

It may be appropriate to change a place where this reflects a change in cultural meanings or practices at the place, but the significance of the place should always be respected.

15.2 Changes which reduce *cultural significance* should be reversible, and be reversed when circumstances permit.

Reversible changes should be considered temporary. Non-reversible change should only be used as a last resort and should not prevent future conservation action.

15.3 Demolition of significant *fabric* of a *place* is generally not acceptable. However, in some cases minor demolition may be appropriate as part of *conservation*. Removed significant fabric should be reinstated when circumstances permit.

15.4 The contributions of all aspects of *cultural significance* of a *place* should be respected. If a place includes *fabric*, *uses*, *associations* or *meanings* of different periods, or different aspects of cultural significance, emphasising or interpreting one period or aspect at the expense of another can only be justified when what is left out, removed or diminished is of slight cultural significance and that which is emphasised or interpreted is of much greater cultural significance.

Article 16. Maintenance

Maintenance is fundamental to *conservation.* Maintenance should be undertaken where *fabric* is of *cultural significance* and its maintenance is necessary to retain that *cultural significance*.

Maintaining a place may be important to the fulfilment of traditional laws and customs in some Indigenous communities and other cultural groups.

Article 17. Preservation

Preservation is appropriate where the existing *fabric* or its condition constitutes evidence of *cultural significance,* or where insufficient evidence is available to allow other *conservation* processes to be carried out.

Preservation protects fabric without obscuring evidence of its construction and use. The process should always be applied:

- where the evidence of the fabric is of such significance that it should not be altered; or
- where insufficient investigation has been carried out to permit policy decisions to be taken in accord with Articles 26 to 28.

New work (e.g. stabilisation) may be carried out in association with preservation when its purpose is the physical protection of the fabric and when it is consistent with Article 22.

Articles

Explanatory Notes

Article 18. Restoration and reconstruction

Restoration and *reconstruction* should reveal culturally significant aspects of the *place*.

Article 19. Restoration

Restoration is appropriate only if there is sufficient evidence of an earlier state of the *fabric*.

Article 20. Reconstruction

20.1 *Reconstruction* is appropriate only where a *place* is incomplete through damage or alteration, and only where there is sufficient evidence to reproduce an earlier state of the *fabric*. In some cases, reconstruction may also be appropriate as part of a *use* or practice that retains the *cultural significance* of the place.

Places with social or spiritual value may warrant reconstruction, even though very little may remain (e.g. only building footings or tree stumps following fire, flood or storm). The requirement for sufficient evidence to reproduce an earlier state still applies.

20.2 *Reconstruction* should be identifiable on close inspection or through additional *interpretation*.

Article 21. Adaptation

21.1 *Adaptation* is acceptable only where the adaptation has minimal impact on the *cultural significance* of the *place*.

Adaptation may involve additions to the place, the introduction of new services, or a new use, or changes to safeguard the place. Adaptation of a place for a new use is often referred to as 'adaptive re-use' and should be consistent with Article 7.2.

21.2 *Adaptation* should involve minimal change to significant *fabric*, achieved only after considering alternatives.

Article 22. New work

22.1 New work such as additions or other changes to the *place* may be acceptable where it respects and does not distort or obscure the *cultural significance* of the place, or detract from its *interpretation* and appreciation.

New work should respect the significance of a place through consideration of its siting, bulk, form, scale, character, colour, texture and material. Imitation should generally be avoided.

22.2 New work should be readily identifiable as such, but must respect and have minimal impact on the *cultural significance* of the *place*.

New work should be consistent with Articles 3, 5, 8, 15, 21 and 22.1.

Article 23. Retaining or reintroducing use

Retaining, modifying or reintroducing a significant *use* may be appropriate and preferred forms of *conservation*.

These may require changes to significant fabric but they should be minimised. In some cases, continuing a significant use, activity or practice may involve substantial new work.

Article 24. Retaining associations and meanings

24.1 Significant *associations* between people and a *place* should be respected, retained and not obscured. Opportunities for the *interpretation*, commemoration and celebration of these associations should be investigated and implemented.

For many places associations will be linked to aspects of use, including activities and practices.

Some associations and meanings may not be apparent and will require research.

24.2 Significant *meanings*, including spiritual values, of a *place* should be respected. Opportunities for the continuation or revival of these meanings should be investigated and implemented.

Articles

Explanatory Notes

Article 25. Interpretation

The *cultural significance* of many *places* is not readily apparent, and should be explained by *interpretation*. Interpretation should enhance understanding and engagement, and be culturally appropriate.

In some circumstances any form of interpretation may be culturally inappropriate.

Conservation Practice

Article 26. Applying the Burra Charter Process

26.1 Work on a *place* should be preceded by studies to understand the place which should include analysis of physical, documentary, oral and other evidence, drawing on appropriate knowledge, skills and disciplines.

The results of studies should be kept up to date, regularly reviewed and revised as necessary.

26.2 Written statements of *cultural significance* and policy for the *place* should be prepared, justified and accompanied by supporting evidence. The statements of significance and policy should be incorporated into a management plan for the place.

Policy should address all relevant issues, e.g. use, interpretation, management and change.

A management plan is a useful document for recording the Burra Charter Process, i.e. the steps in planning for and managing a place of cultural significance (Article 6.1 and flow chart). Such plans are often called conservation management plans and sometimes have other names.

The management plan may deal with other matters related to the management of the place.

26.3 Groups and individuals with *associations* with the *place* as well as those involved in its management should be provided with opportunities to contribute to and participate in identifying and understanding the *cultural significance* of the place. Where appropriate they should also have opportunities to participate in its *conservation* and management.

26.4 Statements of *cultural significance* and policy for the *place* should be periodically reviewed, and actions and their consequences monitored to ensure continuing appropriateness and effectiveness.

Monitor actions taken in case there are also unintended consequences.

Article 27. Managing change

27.1 The impact of proposed changes, including incremental changes, on the *cultural significance* of a *place* should be assessed with reference to the statement of significance and the policy for managing the place. It may be necessary to modify proposed changes to better retain cultural significance.

27.2 Existing *fabric, use, associations* and *meanings* should be adequately recorded before and after any changes are made to the *place*.

Article 28. Disturbance of fabric

28.1 Disturbance of significant *fabric* for study, or to obtain evidence, should be minimised. Study of a *place* by any disturbance of the fabric, including archaeological excavation, should only be undertaken to provide data essential for decisions on the *conservation* of the place, or to obtain important evidence about to be lost or made inaccessible.

Articles

28.2 Investigation of a *place* which requires disturbance of the *fabric*, apart from that necessary to make decisions, may be appropriate provided that it is consistent with the policy for the place. Such investigation should be based on important research questions which have potential to substantially add to knowledge, which cannot be answered in other ways and which minimises disturbance of significant fabric.

Article 29. Responsibility

The organisations and individuals responsible for management and decisions should be named and specific responsibility taken for each decision.

Article 30. Direction, supervision and implementation

Competent direction and supervision should be maintained at all stages, and any changes should be implemented by people with appropriate knowledge and skills.

Article 31. Keeping a log

New evidence may come to light while implementing policy or a plan for a *place*. Other factors may arise and require new decisions. A log of new evidence and additional decisions should be kept.

Article 32. Records

32.1 The records associated with the *conservation* of a *place* should be placed in a permanent archive and made publicly available, subject to requirements of security and privacy, and where this is culturally appropriate.

32.2 Records about the history of a *place* should be protected and made publicly available, subject to requirements of security and privacy, and where this is culturally appropriate.

Article 33. Removed fabric

Significant *fabric* which has been removed from a *place* including contents, fixtures and objects, should be catalogued, and protected in accordance with its *cultural significance*.

Where possible and culturally appropriate, removed significant fabric including contents, fixtures and objects, should be kept at the place.

Article 34. Resources

Adequate resources should be provided for *conservation*.

Words in italics are defined in Article 1.

Explanatory Notes

New decisions should respect and have minimal impact on the cultural significance of the place.

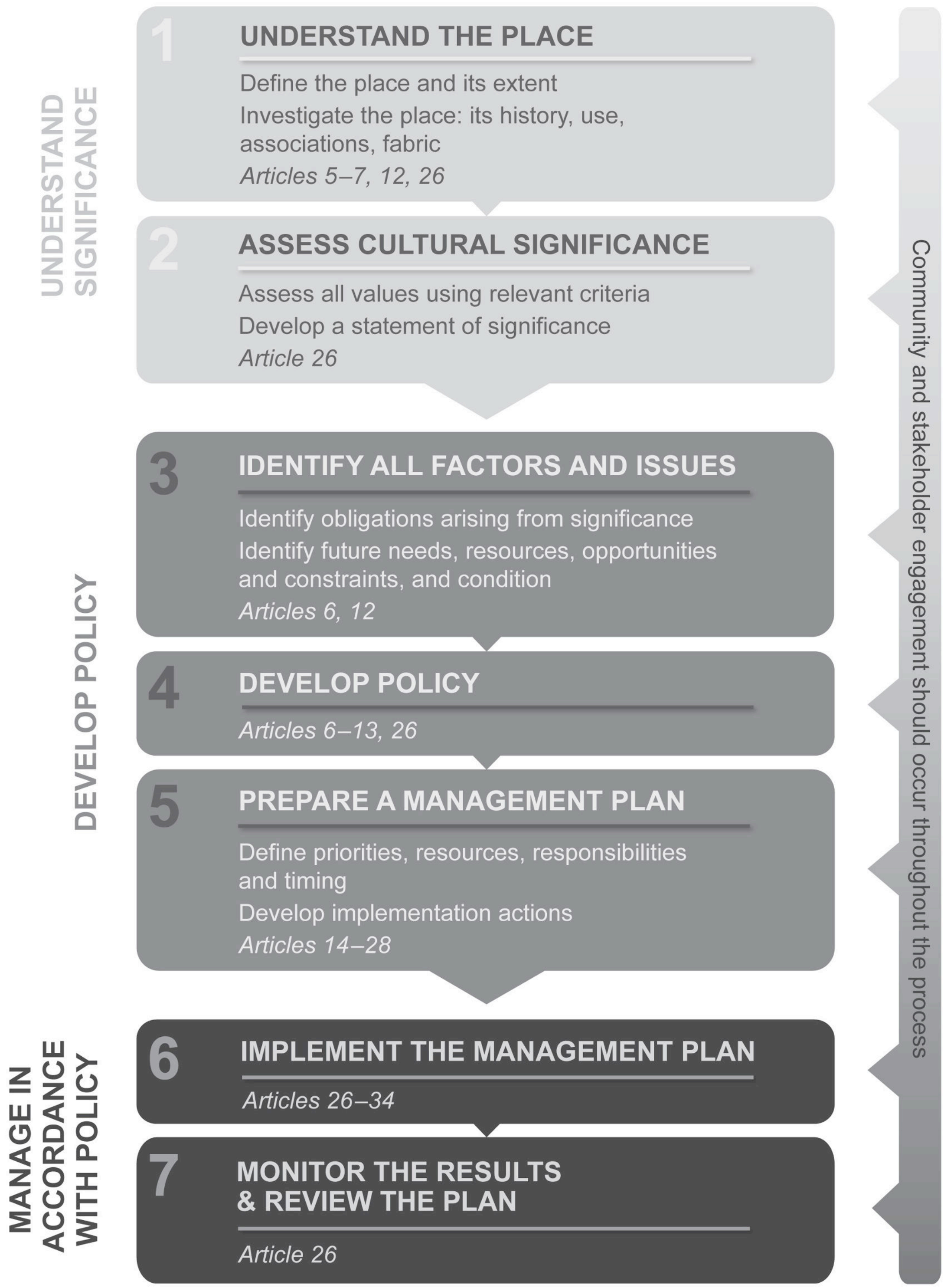
The best conservation often involves the least work and can be inexpensive.

The Burra Charter Process

Steps in planning for and managing a place of cultural significance

The Burra Charter should be read as a whole.

Key articles relevant to each step are shown in the boxes. Article 6 summarises the Burra Charter Process.



16. PRIMARY GENERAL REFERENCES

TECHNICAL

1. "Appraisal of Existing Structures" (3rd ed.), Institution of Structural Engineers, 2010*

2. "Guidelines for Structural Condition Assessment of Existing Buildings" (SEI/ASCE 11-99) -American Soc. Civil Engineers, 2000*

3. "Structural Renovation of Traditional Buildings" Report R111, Construction Industry Research and Information Association (UK), 1986*

4."Engineering Heritage & Conservation Guidelines", Engineering Heritage Australia, Engineers Australia, 2014 (downloadable)*

5. "Historical Structural Steelwork Handbook", Publication 11/84, British Constructional Steelwork Association, 1984

6. Beckmann, P. & Bowles, R.: "Structural Aspects of Building Conservation", Elsevier – Butterworth – Heinemann, 2004

7. Macdonald, S.: "The Investigation and Repair of Historic Concrete" (Parts 1 & 2), New South Wales Heritage Office, 2003 (downloadable)

8. "Conservation Compendium" series in *The Structural Engineer* journal, January 2015 to August 2016

9. Feilden, B.: "Conservation of Historic Buildings", Routledge, 2007

10. Walker, M., Marquis-Kyle, P.:"The Illustrated Burra Charter", Australia ICOMOS, 2004*

11. "Iron and steel bridges: condition appraisal and remedial treatment", Report C664, CIRIA, 2008 (downloadable)

12. Irving, R., Powell, R & Irving, N.: "Sydney's Hard Rock Story: the cultural heritage of trachyte" Heritage Publishing, 2014

13. Burns, J.A. (ed.): "Recording Historic Structures" , National Park Service USA (Wiley, 2004)

HISTORICAL

14. Jack, I. & Cremin, A.: "Australia's Age of Iron", Oxford U. P., 1994

15. Cowan, H. J.: "From Wattle & Daub to Concrete & Steel: The Engineering Heritage of Australia's Buildings", Melbourne U. P., 1998

16. Irving, R.: “Paradise, Purgatory, Hell Hole: The Story of Saunders Quarries”, Media Masters, 2006

17. Lewis, M. (ed.): “200 Years of Concrete in Australia”, Concrete Institute of Australia, 1988

18. O’Connor, C.: “Spanning Two Centuries: Historic Bridges of Australia”, University of Queensland Press, 1985.

The publications marked with an asterisk are all currently in print and possession of (or access to) them is considered vital to a serious approach to the study of the subject.