

Guide to Historical Reinforcement

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Abstract: Many older buildings and structures need to be assessed for their load carrying capacity as part of upgrade or refurbishment works, or simply to ensure the existing structure is capable of carrying specific loads. Examples include the conversion of old warehouse structures into modern office or residential buildings, or checks of the load carrying capacity of suspended floors to take increased loads such as compactus loading. In order to allow analysis of the reinforced concrete structure, the design properties of the steel reinforcement must be known. By knowing when the structure was built, it is possible to determine the type of reinforcement that was available at the time, and hence the design properties of the reinforcement incorporated in the structure for use in the design check or analysis. As many of the older Standards and publications providing this information are either no longer publically available or very difficult to obtain, the Steel Reinforcement Institute of Australia (SRIA) has been working on a new publication to try and capture this important information while it is still accessible, and make it available to engineers in a single comprehensive Guide. The Guide is being developed as questions concerning the properties of historical reinforcement are the most common questions received by the SRIA. This paper is based on the new Guide and provides a summary of the different types of reinforcement available in Australia since the first reinforced concrete structure in 1896, along with the reinforcement material properties to use when checking the design capacity.

Keywords: Reinforcement, Historic, Properties, Guide

1. Introduction

The use of reinforced concrete in Australia began when the contract to build the Johnstons Creek Sewer Aqueduct in Annandale, Sydney was awarded to Carter, Gummow & Co. in 1895. The aqueduct is still in service today and is a testament to the durability of reinforced concrete structures. Combined with the Fyansford and Anderson bridges in Victoria (by John Monash) and the Lamington bridge in Queensland (1896), reinforced concrete was established as the new building material.

In the beginning, reinforced concrete was known by names such as ferro-concrete, concrete iron and steel-concrete construction, and the new reinforcing materials were all produced by companies that had patents over their products. Hence reinforced concrete was often referred to as the Hennibique, Thacher, Melan or Monier Systems. Details of these old reinforcing systems are still available in some older textbooks of the period.

Since its introduction, there have been significant advances in the manufacture and properties of steel reinforcement. This paper seeks to briefly provide some of the key changes that have taken place, and cover some of the properties of the various historic reinforcing products that have been available, so that engineers checking older or historic buildings may have a greater understanding of the properties of the reinforced concrete that was used in their construction. Many of the technical enquiries received by the SRIA relate to historic reinforcement and while information is available, care should be exercised when applying modern design practices to older structures.

2. Development of reinforcement

The use of reinforcement dates back to the mid-18th century where a French gardener, Joseph Monier, used small metal rods as reinforcement for garden tubs and pots, and took out a series of patents for the system. Other systems such as the Melan and Hennebique systems were developed in the early 1890's and the use of reinforcement spread quickly around the world, with its use in bridges commencing in the same decade. One such proprietary system consisting of expanded metal lath as reinforcement was used quite effectively in the construction of some concrete reservoirs built in the 1910s.

Early reinforced concrete structures tended to be modelled after the more familiar masonry, wood and steel structures, hence the Johnstons Creek aqueduct incorporated arches, similar to the masonry arch structure which was first proposed for this project. In the early stages, development was rapid, and often reinforced concrete construction was being utilised prior to the theory being adequately understood. Particularly with respect to flat slab floors which started being used in 1906, typically rule-of-thumb methods were used to proportion the slabs. However, the fundamental principles were known, and many satisfactory structures were built that have stood the test of time and in some cases, significant overloading.

Concrete technology was in its infancy and generally concrete was mixed by hand and proportioned by volume, with standard covers allowed depending on basic exposures such as internal, exposed to

weather and footings. Generous covers and oversized concrete mixes are probably the reason for the durability of some of these early structures such as the Johnstons Creek aqueduct, which although repaired in the late 1990s, is still in use today **Figure 1**.

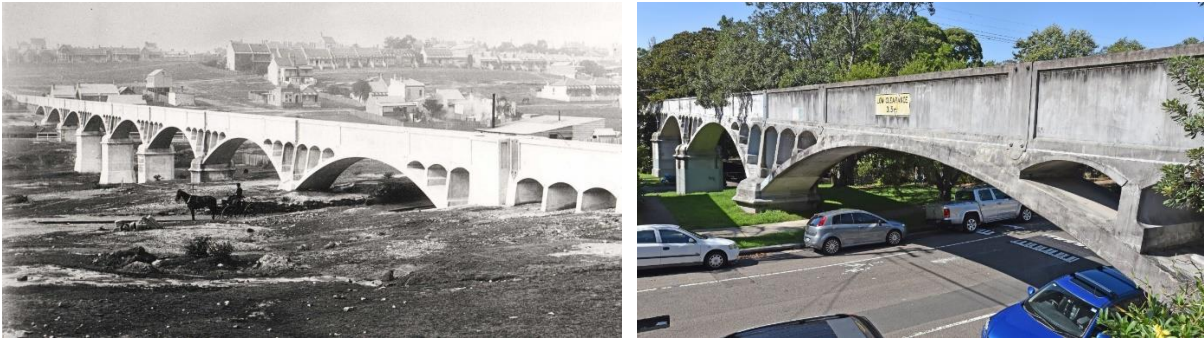


Figure 1 Johnstons Creek Aqueduct: 1896 (left) and 2017 (right)

In terms of reinforcement, the early reinforcing bars were either plain round or potentially square bars in typical sizes ranging from ¼ inch to one and a quarter inches, with a 0.2% proof stress or yield of 230 MPa. Note that tests on some early Monier reinforcement, have given a 0.2% proof stress of 260 MPa. From this early beginning, the strength has gradually increased through greater understanding of the metallurgy and improved manufacturing technology and processes **Table 1 and Figure 2**. Square twisted and twisted deformed bars are strain hardened by twisting to improve their tensile strength, as were intermediate grade, hard grade and twisted deformed bars. In 1983, the process was changed to one of quenching and self-tempering (QST) the bars to achieve the improved strength, durability and weldability of the hot-rolled deformed bars. For high seismic applications, microalloy bars that achieve their strength by alloying the steel mainly with vanadium and nickel provide strength with improved ductility.

Table 1 Development of reinforcing bar properties

| Bar Type | Introduction (year) | Yield Stress (MPa) | Probable Yield Stress (psi) |
|-----------------------------|---------------------|--------------------|-----------------------------|
| Plain round | 1895 | 230 | 33,600 |
| Deformed | 1920's | 230 | 33,600 |
| Square twisted | 1957 to 1963 | 410 | 60,000 |
| Intermediate grade deformed | 1960 to 1968 | 275 | 40,000 |
| Hard grade deformed | 1960 to 1968 | 345 | 50,000 |
| Twisted deformed (CW.60) | 1962 to 1983 | 410 | 60,000 |
| Hot-rolled deformed (410Y) | 1983 | 410 | - |
| Hot-rolled deformed (400Y) | 1988 | 400 | - |
| Hot-rolled deformed (500N) | 2000 | 500 | - |



Figure 2 A chronology of reinforcing bar types

A less common form of reinforcement called up in the first SAA Code for concrete buildings (No. CA. 2 - 1934) was known as twin twisted reinforcement, where two round bars were twisted together helically without altering their length to provide an increased steel area. By not altering the length during twisting, the bars were strain hardened to provide an increased yield strength. The bars were only permitted to be used in tension in one-way slabs, and only $0.45f_{sy}$ or a maximum of 179 MPa was permitted as a working stress. They were specified by the diameter of the individual component bars.

3. History of reinforcement in Australia

Much of the reinforcement in the early years, and in particular from 1911 was imported into Australia from the British Reinforced Concrete Engineering Company Limited (B.R.C.) through their representative B.F. Cox. Due to the cost of importing mesh product, an Australian company known as the Australian Reinforced Concrete Engineering Company Proprietary Limited (A.R.C.) was established in 1919 and in the early months of 1920, mesh was being manufactured at the plant in Sunshine in Melbourne. In the same year that the first blast furnace in Port Kembla was commissioned by Australian Iron and Steel Limited (29th August 1928), A.R.C. opened a manufacturing factory in NSW.

During the early 1920s, A.R.C. obtained its raw materials – wire for the mesh and steel for the reinforcing bars – from B.H.P. Due to the questionable quality of the product supplied, wire was still imported from England until the quality of local supplies improved towards the late 1920s, demonstrating that product quality has always been a focus of the industry. A.R.C.'s early prosperity was associated with the tremendous demand for concrete in the 1920s, particularly supplying rolled mesh product for concrete roads (**Figure 3**), railways, harbor work, water supplies and sewerage. There was also increasing demand from the private sector in the 1920s, with production reaching a peak of 7,034 tons in 1929.



Figure 3 Rolled mesh used on Melbourne tram track foundation (left) and Walker Street, North Sydney (right)

The 1930s depression revealed the dangers of relying on the demand from a volatile building industry and the company set about diversifying its product range. By 1935, products such as weldmesh for fencing and fabricated units for lintels, beams and columns, brick reinforcements and mild steel rounds in stock lengths, bent, cut or fabricated, were being produced. So prefabrication of reinforcement was being used as early as 1935.

Demand gradually grew, with the Second World War years seeing 98% of A.R.C.'s production used for defense purposes, leaving reinforcing products in short supply for the building industry for many years after the war. Increasing demands for mesh supply from British civil and military contracts in south-east Asia at a time when the company was already struggling to meet home defense needs made the situation worse. The barbed wire product known as 'Barblok' became successful during this time. The late forties was categorized by rationing and other controls.

The 1950s was a time of sustained growth and expansion for the industry, with continual improvement in technical capacity as well. The purchase of the Ovaweld company in South Australia in 1948 widened A.R.C.'s market, strengthening the company in South Australia and laying the foundation for present day operations. The decision to import raw materials in 1949 to remove a bottleneck in supply from BHP, ensured the growth of the company through the 1950s as supply to major contracts could be guaranteed.

There were few problems in the 1960s with significant capital expenditure on plant modernisation and building, setting the company up for further growth in the 1970s and beyond, with A.R.C. now producing reinforcement in every State in Australia from the early 1960s. The company has adapted to new

technology over the years and led the development and manufacture of various innovative reinforcing products supported by design literature for building efficiencies.

In 1982, A.R.C. was acquired by Humes and the business becomes known as Humes ARC. In 1983, Smorgon Steel commissioned the electric arc furnace in Laverton, Melbourne and the rolling mill was commissioned in the following year. Smorgon Steel manufactured a range of products including steel rod, bar and tubing. In 1987, Smorgon Steel merged with Humes ARC, only to take over the remaining Humes ARC shares in 1988 and return ownership of the steel business back to the Smorgon family (Humes ARC re-branded as Smorgon ARC).

In response to Smorgon's electric arc furnace, BHP commissioned a Mini Mill in Rooty Hill, Sydney in 1992. When BHP divested in 2000, ownership of this asset passed to OneSteel (Arrium) and it became known as the Sydney Steel Mill. OneSteel acquired the Smorgon Steel Group in 2007, including the electric arc furnace in Laverton, Melbourne and Arrium is now the only manufacturer of reinforcement in Australia. In 2008, OneSteel re-branded Smorgon Steel Reinforcing as the Australian Reinforcing Company (ARC) in recognition of the long heritage of quality reinforcement manufacture in Australia. Thus ARC today continues to manufacture reinforcing product from the original 1920 Sunshine facility in Melbourne. Together with a number of other SRIA member companies, steel reinforcing bar is processed and wire from the mills is manufactured into mesh product for various projects.

4. Dimensional properties of reinforcement

As well as gradually improving the strength over time, a major change to the industry occurred in 1970. This was the beginning of metrication, which was introduced over the next five years. One of the most common questions received by the SRIA concerns the properties of imperial sized reinforcing bars and fabric (now referred to as mesh). **Tables 2 and 3** provide a summary of these older imperial properties. While **Table 3** provides details of square fabrics, rectangular (or 'oblong' fabrics as they were known) as well as some other sizes were also available.

Table 2 Dimensional and properties of imperial deformed round steel bars
(after Table II of A.S. No. A.92-1958 (1) and Table 1 of A.S. A.92-1965 (2))

| Deformed Bar Designation Number* | Unit weight | | Effective Dimensions | | | |
|----------------------------------|-------------|--------|----------------------|-------|----------------------|--------------------|
| | | | Diameter (d) | | Cross sectional area | |
| | (lb/ft) | (kg/m) | (in) | (mm) | (in ²) | (mm ²) |
| 3 | 0.376 | 0.599 | 0.375 | 9.53 | 0.11 | 71 |
| 4 | 0.668 | 0.994 | 0.500 | 12.70 | 0.20 | 129 |
| 5 | 1.043 | 1.552 | 0.625 | 15.88 | 0.31 | 200 |
| 6 | 1.502 | 2.235 | 0.750 | 19.05 | 0.44 | 284 |
| 7 | 2.044 | 3.041 | 0.875 | 22.23 | 0.60 | 387 |
| 8 | 2.670 | 3.973 | 1.000 | 25.40 | 0.79 | 510 |
| 9 | 3.380 | 5.029 | 1.125 | 28.58 | 0.99 | 645 |
| 10 | 4.172 | 6.108 | 1.250 | 31.75 | 1.23 | 794 |
| 11 | 5.049 | 7.513 | 1.375 | 34.93 | 1.49 | 961 |

* The Bar Designation Number refers to the bar diameter in multiples of eighths of an inch ie No. 8 bar = 8 x 1/8 in. = 1 inch diameter.

Table 3 Dimensions and properties of imperial square mesh fabrics
(after Table II of A.S. No. A.84-1958 (3))

| Reference | Nominal pitch of wires | Size of wires each way | | Cross-sectional area each way | | Nominal weight | |
|-----------|------------------------|------------------------|-------|-------------------------------|----------------------|-------------------------|----------------------|
| | | (S.W.G.*) | (mm) | (in ² /ft) | (mm ² /m) | (lb/yard ²) | (kg/m ²) |
| 601 | 6 | 1 | 7.620 | 0.1414 | 299 | 8.65 | 4.69 |
| 602 | 6 | 2 | 7.010 | 0.1196 | 253 | 7.32 | 3.97 |
| 603 | 6 | 3 | 6.401 | 0.0998 | 211 | 6.10 | 3.31 |
| 604 | 6 | 4 | 5.893 | 0.0845 | 179 | 5.17 | 2.80 |
| 605 | 6 | 5 | 5.385 | 0.0706 | 149 | 4.32 | 2.34 |
| 606 | 6 | 6 | 4.877 | 0.0579 | 123 | 3.54 | 1.92 |
| 608 | 6 | 8 | 4.064 | 0.0402 | 85 | 2.46 | 1.33 |
| 610 | 6 | 10 | 3.251 | 0.0257 | 54 | 1.58 | 0.86 |

* British Standard Wire Gauge (or Imperial Wire Gauge)

5. Mechanical properties of reinforcement

The British developed a Code of practice for the use of reinforced concrete in 1933 and Australia essentially adopted many of the provisions the next year when CA. 2 was released covering 230 MPa Grade steel bars. Due to rapid innovations in the industry, a revision was released in 1937 to also include medium and high yield point steels for the war. Mild steel bars needed to comply with Australian Standard No. A.1 (4). Both medium and high yield point steels were required to comply with British Standard No. 785 (5) and some restrictions were placed on their use. Because the use of this higher strength steel was still under consideration, it was not permitted to be used in beams or other principal members of reinforced concrete buildings. Its maximum stress was limited to that of mild steel when used for tanks, sewers, drains or conduits carrying water when part of a building structure, or when the building structure was exposed to harmful conditions, or building foundations. Furthermore, the higher stresses could only be used where a high standard of workmanship and supervision was maintained, and only with the express approval of the building owner.

The maximum stresses allowed in CA. 2 for each type of reinforcement in 1937 was as follows:

- Mild steel – increased from 124 (1934) to 138 MPa (1937) due to war emergency provisions
- Medium tensile steels – 152 MPa but not exceeding $0.45f'_{sy}$
- High yield point steels – 179 MPa but not exceeding $0.45f'_{sy}$
- Special reinforcement – as for high yield point steels

The maximum stress allowable was generally limited to $0.45f'_{sy}$ except for the special case of twin twisted bars or wire fabric reinforcement used in one-way slabs, and cracking of the concrete was an issue that needed to be considered.

CA. 2 was further revised in 1963 with an ultimate strength design version released in 1973, and a metric version released in 1974. AS 1480 (6) which superseded CA. 2 was released in 1974, revised in 1982 and then superseded by AS 3600 (7) in 1988 and subsequent revisions in 1994, 2001 and 2009. AS 3600 is currently being revised with the aim to be called up in the 2019 National Construction Code.

The properties of reinforcement moved from AS No. A.1 starting in 1928 to the suite of Standards AS No. A.81, A.82, A.83 A.84 and A.92 in 1958 (8), with AS 1302 (9) released in 1974 and 1303 (10) and 1304 (11) in 1991. The current Standard covering reinforcing products, AS/NZS 4671 (12) was released in 2001. A Project Proposal for the revision of AS/NZS 4671 is under development.

With the development of strain hardening by deforming or cold-twisting the bars in the late 1950's, AS No. A.81 covered reinforcement manufactured from steel in the as-rolled condition, AS No. A.83 covered cold-twisted bars made from material complying with AS No. A.81, and AS No. A.92 covered hot-rolled deformed bars with ribs. In 1965, the requirements for the ribs were deleted from AS No. A.92 and appeared in AS No. A.97 (13).

The minimum yield and ultimate tensile stresses in the 1950s were as follows:

- Mild Grade – yield = 207 MPa and ultimate tensile = 379 to 483 MPa
- Structural Grade – yield = 231 MPa and ultimate tensile = 434 to 517 MPa
- Intermediate Grade – yield = 276 MPa and ultimate tensile = 483 to 621 MPa
- Hard Grade – yield = 345 MPa and ultimate tensile = 552 MPa minimum

Grades other than mild steel needed to be identifiable by special bar markings, to enable checking of the correct reinforcement on site.

AS No. A.83 covered both single cold-twisted reinforcing bars and twin-twisted reinforcing bars. The minimum yield stress and ultimate tensile stress of these bars were as follows:

- Single twisted bars <10 mm diameter or side
Minimum yield of 483 MPa and minimum ultimate of 552 MPa
- Single twisted bars ≥ 10 mm diameter or side
Minimum yield of 414 MPa and minimum ultimate of 483 MPa
- Twin twisted bars <10 mm diameter or side
Minimum yield of 372 MPa and minimum ultimate of 434 MPa
- Twin twisted bars ≥ 10 mm diameter or side
Minimum yield of 372 MPa and minimum ultimate of 434 MPa

A.R.C. introduced an entirely new type of cold twisted deformed Grade 60 (CW.60) bar or 60,000psi yield strength bar in 1963 **Figure 2**. This product emerged after two years of intensive research and was announced as A.R.C.'s best contribution to the industry since the introduction of fabric forty two years earlier. The fact that CW.60 served the reinforcing market for the next 25 years up until 1983 is testament to this claim (note that CW.60 was renamed 410C following metrication). The bars satisfied AS No. A.81 for Grade of parent steel, AS No. A.83 for cold twisting and AS No. A.92 for rib deformations. Also, the guaranteed minimum yield strength of 60,000psi or 410 MPa was within the limits of CA.2 (1963). For

the first time in Australia, the maximum allowable design stresses could be employed in conjunction with the superior bond characteristics of 'standard' A.S.T.M. deformed bars.

In 1983, BHP developed a hot-rolled deformed bar known as TEMPCORE, or Grade 410Y bars, which replaced the older 410C bars (or CW.60 as it was known before metrication). With Smorgon steel commencing production in 1983, they also produced a similar bar known as *Welbend* later that year. These were a quenched and self-tempered (QST) steel bar (rather than cold-twisted) having a minimum yield stress of 410 MPa. In accordance with AS 1302-1982, these bars had to have a minimum upper yield stress of 410 MPa and minimum tensile strength of 1.05 times the upper yield stress.

With the introduction of the hot-rolled deformed 400Y bars in AS 3600 in 1988, AS 1302 was revised in 1991 to both allow the new 400Y bars to be manufactured, and to set limits on the minimum yield stress (400 MPa) and minimum tensile strength (1.1 times the yield stress) of the bars. One of the main benefits of the new QST bars was their ability to be welded. The standard permitted the manufacture of bars by other technologies such as microalloying; maintaining weldability by strict control on the carbon equivalent (C_{eq}). At the same time, grades 250S and 250R replaced grades 230S and 230R respectively.

Fabric properties during this same period needed to comply with AS 1303 and AS 1304, which required a minimum yield strength of 450 MPa.

The quenched and self-tempered (QST) and microalloy Ductility Class 500N, as well as the Ductility Class 500L reinforcing bars which are used in design today were developed in the 1990s and are covered by AS/NZS 4671-2001. For Ductility Class N bars, AS/NZS 4671 specifies a minimum yield stress of 500 MPa, maximum of 650 MPa, with a minimum tensile strength of 1.08 times the yield stress. For Ductility Class L bars, AS/NZS specifies the same minimum yield stress of 500 MPa but an upper limit of 750 MPa, with a minimum tensile strength of 1.03 times the yield stress.

The minimum yield stress of the wires (pre 1995) or deformed bars in mesh (or fabric as it was known prior to AS/NZS 4671) was always 450 MPa, regardless of the manufacturing process. It was increased to 500 MPa in 1995 with the widespread production of cold-rolled deformed bar meshes. Ductility Class L bars (formerly termed wires) used for its manufacture now have to comply with the ductility parameters established in AS/NZS 4671.

6. Designation of reinforcement

Typical methods of designating early reinforcement on drawings were as follows:

- CW.60 reinforcing bars were denoted by using the same numbering system normally used for deformed bars. It was recommended that the deformed bar symbol # be placed in front of the bar number and that the specific reference for CW.60 be 'CW' placed immediately after the bar number. For example, the designation 6 - #4 CW @ 10" would mean six, number 4 size (or 1/2 inch) deformed CW.60 bars laid at 10 inch centres.
- Structural-grade deformed bars to AS A92 and A97 were typically denoted on drawings by an S. For example, 28 S806-9"T meant 28 structural grade deformed bars of size #8 (or 1") to be placed at 9" centres in the top of the slab. The '06' after the bar size (#8) was used to indicate that this was either the 6th set of #8 bars marked on the drawing, or they were the same as other bars marked '06'.
- Structural-grade plain round bars to AS A81 were typically denoted on drawings by a R.
- Hard-grade deformed bars to AS A92 and A97 were typically denoted on drawings by an H (eg #6H = No. 6 hard grade deformed bar).
- Cold-worked deformed bars to AS A83 and A97 were typically denoted on drawings by a C. If the bars were twisted, a T or W may have been added (eg #6CT or #6CW) or they may have been indicated simply as C6 without the #, W or T being added.
- Hard-drawn wire reinforcing fabric to AS A84 was typically denoted on drawings by a F.
- Hard-drawn wire to AS A82 was typically denoted on drawings by a W (today designated by L).

7. Assessment of Historical Reinforcement

The basic principle for assessment of historical steel reinforcement should be "assume the worst and verify the best!" In practice this can be summarised as follows:

- All plain round bars are assumed to be 230 MPa.
- Plain cold-drawn wire was often used in fitments and may be 450 MPa but confirmation of its properties would be required if shear capacity is critical.
- All plain welded fabric is assumed to be 450 MPa.
- Unidentifiable deformed bar is 230 MPa unless verified by bar marks or testing.
- Look for historic documentation.
- Where possible undertake material testing to verify the material and chemical properties.

7.1 Identification of bars

Identification of reinforcing steel prior to the 1980s is reasonably straightforward. Prior to 1957 when strain hardening was introduced, all reinforcement should be taken as having a yield stress of 230 MPa unless testing indicates otherwise. From 1957 to 1983, higher strength steels (intermediate and hard grades) were achieved by twisting structural grade bars, making identification simple by the spiral longitudinal rib **Figure 2**. The 410C bars available from 1963 to 1983 were in fact the renamed CW.60 bars when metrication occurred: hence they can still be identified by the spiral longitudinal rib. The hot-rolled Grade 410Y bars from 1983 to 1988 can be identified by the bar markings (Figures 4a and 4b), with TEMPCORE bars also having the word TEMPCORE embossed on the bar at about one metre centres. From 1988 to 1995, the 400Y bars essentially had the same properties and bar markings. From 1995 all reinforcement manufactured was Grade 500 MPa. Examples of rib patterns are shown in **Figure 4**.

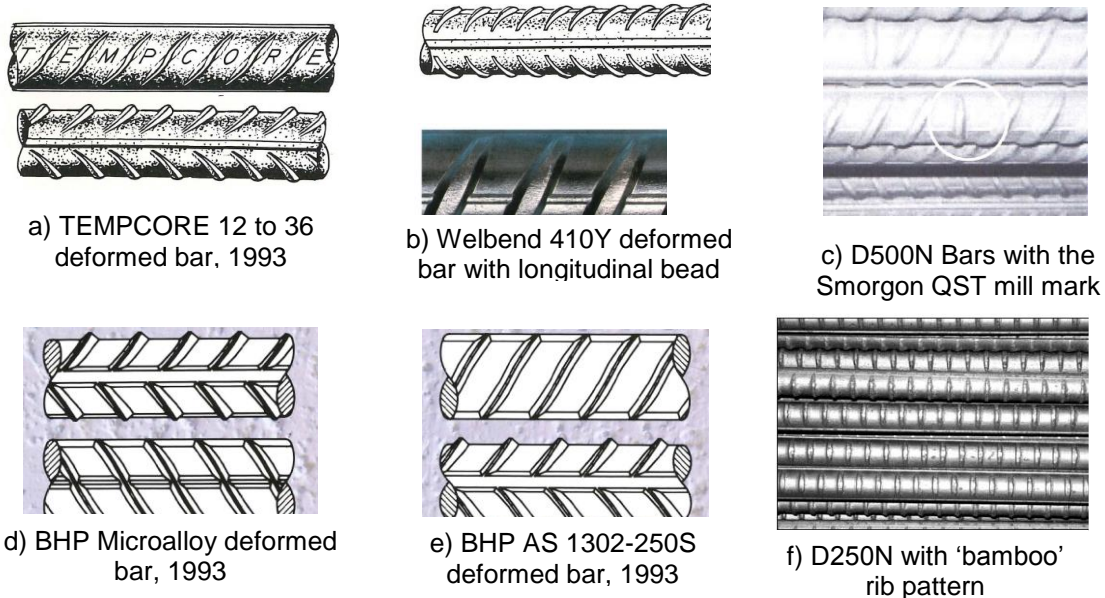


Figure 4 Examples of identifying rib patterns

7.2 Sources of Information

There are many sources of information regarding historical buildings and structures and the reinforcement that was used for their construction, albeit that some information is becoming increasingly difficult to source. Sources of information include:

- **Design Drawings.** If the design engineers or original owners of the structure are known, access to work-as-executed drawings may be possible. Steel reinforcement processors also undertook design up to the 1970s. We understand that details of these projects were preserved as microfilm and may be available. The Historical Reinforcement document will contain typical details indicating how the various types of reinforcement were called up on drawings.
- **Library and Archive material.** Monumental structures may have archive material in State and Local Government libraries. Publicly-owned structures such as schools, water utilities, rail infrastructure etc. usually have well documented information retained by the public authority. The SRIA has been able to extract information on some projects to use as examples of how previous reinforcement material types were called up on drawings.
- **Historic Standards.** Copies of Australian Standards A.1 dating back to 1928; A.81, A.82, A.83, A.84, A.92 and A.97 dating back to 1958 and 1965 are available/retrievable from SAI Global. SAI Global does not have a copy of AS A97-1965. These standards were replaced by AS 1302, 1303 and 1304 in 1991; and ultimately replaced by AS/NZS 4671 in 2001. There is also an interim wartime specification for "Arcmesh" which was also published by the then Standards Association of Australia. The majority of these are still available but at a considerably increased cost compared to the two shillings some of them originally cost. Note that relevant information from these Standards has been included in the Historical Reinforcement document.

7.3 Testing

Where possible, a sample of bar should be retrieved from the structure under consideration. The condition of the bar can be assessed visually for evidence of corrosion and loss of volume of steel, and tested to determine its mechanical properties.

- **Tensile testing**

A tensile test will reveal yield strength, tensile strength and uniform elongation; all essential requirements for current design practices.

- **Spectrographic analysis.**

Spectrographic analysis can be used as a stand alone or in conjunction with tensile testing. The chemical composition of the steel is analysed by a sparked sample. The analysis measures the quantities of elements including C, Mn, Cr, Mo, V, Ni and Cu and can be used to calculate a carbon equivalent (C_{eq}). This gives a measure of the weldability of the steel. Low C_{eq} steels are usually more weldable than higher C_{eq} steels, with the precaution that cold-worked bars revert to their parent base (taken to be 230MPa) unless precautions and practices are adopted as noted in Section 8.

- **Hardness Testing**

Where a tensile test is not possible, a hardness test, in conjunction with the spectrographic analysis, will give an approximate indication of material strength. Typical hardness tests include Vickers, Rockwell and Brinell. Laboratories associated with Australian steel mills prefer the Vickers test. Its results can be calibrated to an ultimate tensile f_{su} and a yield strength f_{sy} estimated at $0.6 f_{su}$.

As an example, a number of years ago, the SRIA received a small sample of an expanded metal lath, which had been used to reinforce a concrete reservoir built around 1915. The sample size was insufficient for tensile testing but the spectrographic analysis and hardness testing enabled a conclusion that the steel possessed a relatively high yield strength (thanks primarily to the cold-work effects of slitting and expanding the metal). The information gleaned from the testing assisted in the determination of the serviceability and integrity of the structure.

8. Splicing to historical reinforcement

Unlike the modern reinforcement steels, early 20th century reinforcements must be unmistakably identified or metallurgical testing performed in order to undertake suitable welding procedures. An early blueprint drawing may identify the reinforcement material intended for the historic project but this may not be entirely accurate and designers need to be sure that the specified material was actually procured for the project. Material substitution and quality of materials from other Australian manufacturers or importers is a potential factor even in the pioneering days of reinforced concrete construction. The design drawings are however a good starting point for the quality of the reinforcement and as built arrangement but the real true test is to sample from the structure for spectrographic analysis of material properties (refer Section 7.3).

From the ARC Reinforcement Handbook (14) the historical reinforcement splicing guidelines in Appendix C indicate that the twisted square bars from 1957 to 1963 are able to be joined by removing the untwisted ends (about 150-200mm) that were held in the grips for the twisting process and therefore not strain hardened, before splicing by end-butt welding or mechanical methods. However, not knowing where the mechanical working and therefore uniform bar properties commence (ie 410MPa material), it is still highly recommended to assume a 230 MPa yield strength.

Intermediate Grade deformed reinforcement from 1960 to 1968 was rare for construction in Australia and likely projects are those designed in the USA or to ASTM Standards. Weldability is very doubtful (with generally high C_{eq} values from the USA) and it should be considered as not weldable.

Hard Grade deformed reinforcement from 1960 to 1968 was common in NSW but unusual elsewhere and this material is not weldable.

A noticeable change to the weldability of reinforcing steels, as we expect today provided the welding complies to AS/NZS 1554.3, commenced with the A.R.C. development and introduction of Twisted deformed CW.60 reinforcing bar that was available from 1963 through to 1983. The ARC CW.60 Technical Data publication (15), detailed that CW.60 cold-worked reinforcing steels can be satisfactorily joined by welding provided that several precautions are observed both during the design stage and in carrying out of welding operations. Experiments were carried out to determine the effects of:

- Flash butt-welding bars together
- Welding bars to an anchor plate
- Tack-welding cross rods to the bars

In all cases when these bars were tested, the failures occurred in the parent steel outside the heat affected zone. In the case of the butt-welded and cross-rod welded bars, an extensometer placed over the weld during testing indicated that the proportionality and the elastic modulus were not affected.

In these experiments the results were achieved without strict laboratory control of the welding operations, the welds therefore being of a standard and expected of site welding. A.R.C. still **strongly**

recommended that even when all design precautions are taken, the welding of cold-worked steel should be carried out only by competent operators under proper supervision. This is no different to the requirements of AS/NZS 1554.3 today.

Some welding rules included were that welds should not be located at angles or bends of reinforcing bars, located at places of reduced stress, not more than 20% of reinforcing bars welded at the one point and for deformed bars joints separated by at least 10 bar diameters plus loading limits to 80% depending on welding supervision employed.

From 1983 all reinforcement was reported as weldable.

9. Typical Detailing

According to the Cement and Concrete Association of Australia (CCAA) in the 1970 publication *Reinforced concrete detailing manual* "Most designers and draftsmen have their favorite methods of detailing reinforced concrete; unfortunately not all of these achieve the basic requirements of clarity and conciseness."

For this reason, A.R.C. produced various industry guides in the 1960s and 1970s that promoted 'standard' detailing practices. Various industry Associations such as the CCAA and CIA also later produced similar publications, and much of this early pioneering work is now contained in the Concrete Institute of Australia's publication *Reinforcement Detailing Handbook* (first published in 1968, revised in 1973, 1976, 1989 and 2011).

Examples of how reinforcement was detailed in 1970 are shown in **Figures 5 and 6**. The typical practice of cranking the bars at the inflexion points of beams and slabs can be seen in **Figure 7**. Note that the letter after the bar designation refer to the shape of the bar. For example, the notation for beam fitments 5R301ST-12" means 5 round bars (R) of size 3 (or 3/8 inch) of shape ST (which can be seen in the beam cross section) at 12 inch centres. The 01 after the bar size is intended to indicate all bars on the drawing labelled 01 are the same.

10. Conclusions

The development of the SRIA new Historical Reinforcement publication has emphasised the importance of maintaining our technical history. We are often asked for guidance in the determination of what might be the appropriate design properties of reinforcement in older buildings, and as time goes by, the information is becoming more difficult to source. As a result, we have attempted to bring what knowledge is available into a single document to capture this important information about our industry, for the benefit of all those that need to check the design of historical buildings. This paper represents only a very small portion of the information that will be available in the actual Historical Reinforcement publication.

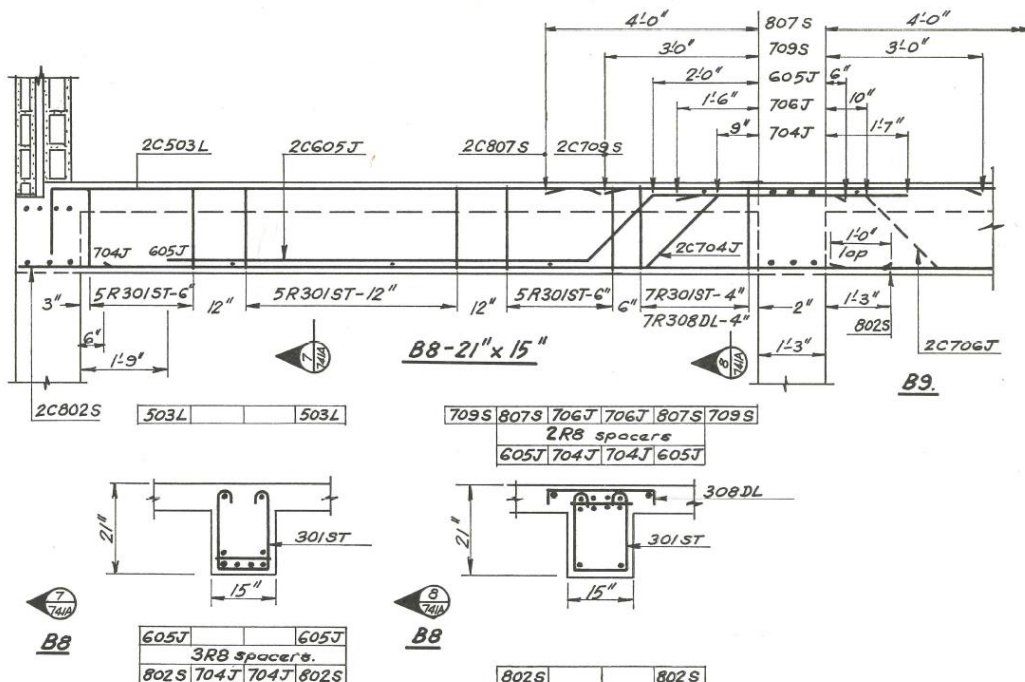


Figure 5 Typical beam detail (CCAA, Reinforced concrete detailing manual, 1970)

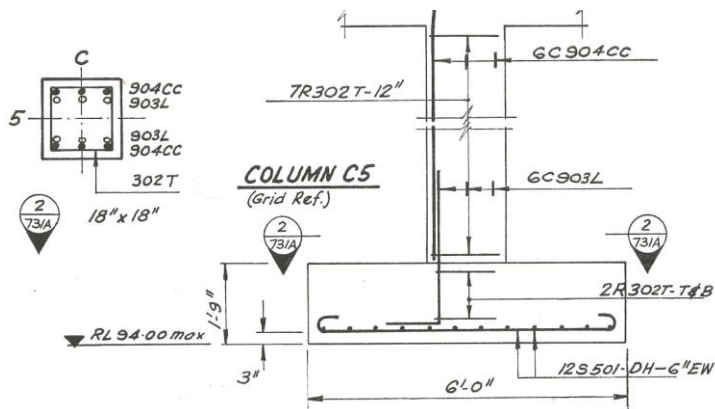


Figure 6 Typical column detail (CCAA, Reinforced concrete detailing manual, 1970)

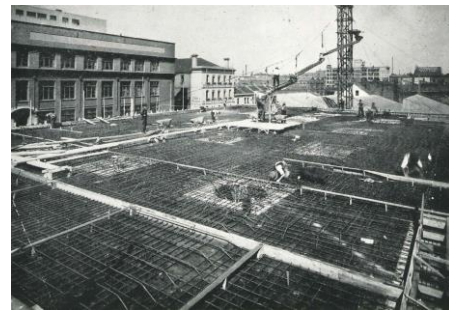


Figure 7 Flat slab floor to garage (A.R.C. Reinforcements, 1953)

In particular, we would emphasise that the preservation of work-as-executed documents by design offices and builders is critical. The low cost of digital storage especially in the “cloud” should reduce the excuses for not retaining this information, and hence having it available if and when required. In the public sector a program known as “As designed As constructed” ADAC (adac.com.au) may provide a means for holding essential data for asset management of public infrastructure.

Also, design offices should not discard their old referenced standards, as these may be necessary in the future, and while many are still available from Standards Australia, they tend to be very expensive.

Future developments include the investigation of high-strength reinforcing steels up to a potential of 750 MPa. With each new development, the SRIA will ensure that our historical reinforcement document is kept updated for the benefit of future generations.

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