Guide to Historical Steel Reinforcement in Australia

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Abstract: This paper is based on the Steel Reinforcement Institute of Australia (SRIA) new *Guide to Historical Reinforcement in Australia* and provides a summary of information contained in the Guide. The Guide is the result of the most common technical enquiry received at SRIA and provides properties of past reinforcement types, interpretation of the notation used on older drawings, and guidance on checking the design capacity of historic reinforced concrete (RC) buildings and structures.

The Guide also summarises the social and economic environment within key time periods during reinforcement development in Australia to enable Engineers to understand how RC structures were built during a particular period, and the important aspects of design and construction that need to be considered when checking the capacity of older reinforced concrete structures.

The life of reinforced concrete structures is typically far in excess of its design life. Australia's first RC structure built in 1895, the Johnstons Creek Sewer Aqueduct in Sydney, is still in service today. Replacing existing structures prematurely is not sustainable, and hence the need to maintain heritage and re-purpose existing concrete buildings and structures is increasing. Sourcing knowledge about the materials used to allow design checks to be undertaken is therefore essential.

Keywords: Reinforcement, Historic, Properties, Standards, Design.

1. Introduction

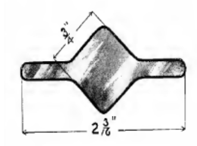
Most technical enquiries received by the SRIA relate to the designation and corresponding tensile design properties of historical reinforcement. As many of the older printed Standards and publications providing the necessary design information are either no longer publically available or extremely difficult to obtain, the aim of the new *Guide to Historical Steel Reinforcement in Australia*, is to bring this information together into a single resource for the design profession. The Guide also provides information on other factors that need to be consider when assessing historical structures such as the evolution of design theory and detailing, batch and strength of concrete, variability of materials, Standards development, industry technical information and construction techniques. Guidance on interpreting old imperial designations of reinforcement with project examples is also included. The Guide and this paper are divided into key time periods based on major developments in steel reinforcement since it was first used in Australia in 1895.

2. The Early Years (1895 to 1920)

During this period a variety of patented systems, usually based on the developer's name, were adopted for use in Australia. Some of the systems used in Australia during this period included the Monier (which dominated), Hennebique, Kahn, Considere, Coignet, Ransome and Habrich systems, as well as Johnson and Thacher bars, hollow tile or Innis-Bell systems and expanded steel systems (**Figure 1**).

The first reinforcement system used in Australia was the Monier system after Frank Gummow in Australia bought the rights for the system and constructed the Johnstons Creek aqueduct (**Figure 2)** from 1895 to 1896. Frank Gummow sold the rights for the system in South Australia and Victoria to John Monash. Between Frank Gummow and John Monash there were many projects constructed using the Monier arches such as the Lamington Bridge in Queensland (1896) and the Fyansford Bridge in Victoria (1899). The first use of RC by NSW Railways was an 8" thick arch over bridge at Hilltop completed in 1899 (**Figures 3 & 4**).

In the early stages, development was rapid, and often reinforced concrete construction was being ulitised prior to the theory being adequately understood. This is demonstrated by Julius Kahn who was quoted as saying that in the early days of the Kahn System, he determined the structural design "*by guess. There are no scientific data*". With respect to flat slab floors which started being used in 1906, typically rule-of-thumb methods were used to proportion the slabs. Codes of practice setting out minimum requirements did not exist until the 1920s.

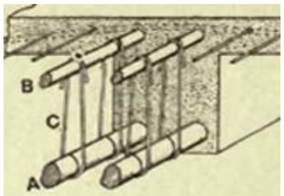


Kahn bar

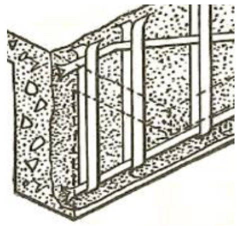
Ransome bar

Thacher bars

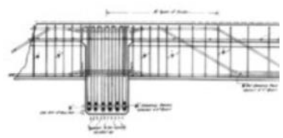
Johnson (or corrugated) bars



Coignet System

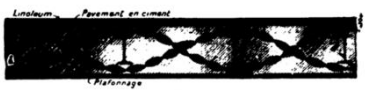


Hennebique System



Monier System

Expanded mesh



Habrich System

Hollow Tile or Innis-Bell System

Figure 1. Examples of patented steel reinforcement systems

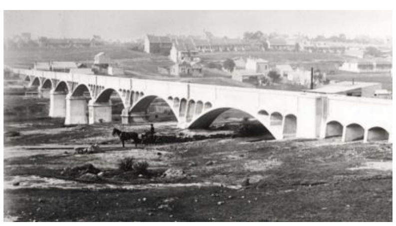


Figure 2. Johnstons Creek Aqueduct, 1896

Figure 3. Monier arch bridge at Hilltop, 1899 (photograph 2019)

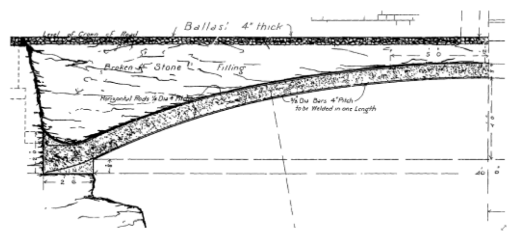


Figure 4. Structural details of Monier arch bridge at Hilltop, 1899

According to initial reports on the properties of reinforcement the minimum tensile yield strength of reinforcement was generally above 200 MPa, and because reinforcing bars were all smooth round or rectangular/square bars, the main challenge was how to effectively anchor the ends of the bars within the concrete to more fully utilise the tensile strength of the bars within the design. Most of the different proprietary systems were based on alternate methods of anchoring the bars. For example the Monier System (**Figure 5**), which used plain round bars, were anchored by bending the bars into the opposite side of the slab or beam, or providing a hook at the end of the bar. The Kahn Trussed bars were anchored by shearing the edges of a flat bar and bending them up at a 45 degree angle, the Hennebique System relied on 'fishtail' ends on the bars for anchorage, Johnson bars were corrugated and Ransome Bars were cold twisted for anchorage (**Figure 1**).

As all reinforcement in this period was imported into Australia from various sources, unless testing reveals a higher strength, it is best to assume no more than 200 MPa as a tensile yield strength. Some textbooks and industry reports existed during this period, with both British [1] and American [2] reports stating that generally a working stress of 110 MPa should be used for the reinforcement, and 4 MPa for the concrete. The maximum concrete strength for a good quality 1:1:2 (cement:sand:aggregate) concrete mix was listed as 23 MPa, with a 1:2:4 mix achieving 15 MPa.

When assessing structures of this period, not only does the type and strength of the bar need to be considered, but also the reinforcement detailing, as the anchorage of the tensile reinforcement may not allow the full tensile strength of the bar to be developed, and the effectiveness of any shear reinforcement will typically not meet today's Standards.

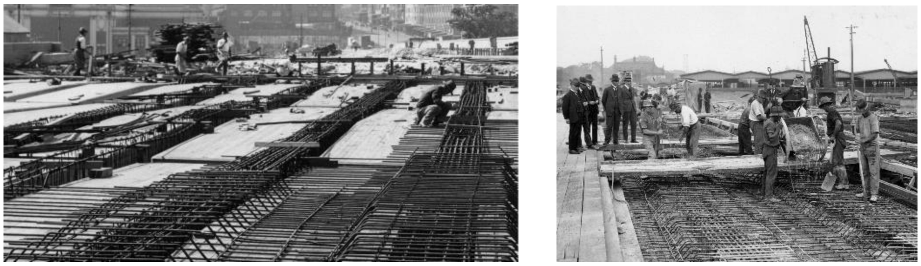


Figure 5. Monier System with bars bent into the top or bottom of the slab/beam (left) and concrete placement (right) on Eddy Avenue Bridge, Sydney, 1925 (ARHS RRC517458 left and 517470 right)

3. Period from 1920 to 1957

BHP commenced steel manufacture in Australia in 1915, and by 1920 was rolling structural grade 208 MPa round bar. Having a local source of material, it was clear to the British Reinforced Concrete Engineering Company Limited (B.R.C.), who had been exporting large quantities of reinforcement to Australia since 1911, that they would have to consider local manufacture. The Australian Reinforced Concrete Engineering Company Proprietary Limited (A.R.C.) was established in 1919 and in early 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. 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 6**), railways, harbour work, water supplies and sewerage.

Figure 6. Rolled mesh used on Walker Street, North Sydney

In terms of reinforcement properties, with local manufacture and increasing use of reinforced concrete, 1920 saw the publication of the Australian Standard Specification for Structural Steel [3], which recommended that the tensile breaking strength of round and square bars (which were used for reinforcement) be in the range of 430 to 510 MPa (28 to 33 tons/in.^{2}), with an elongation of not less than 20%. This was superseded in 1928 by the publication of Australia's first Standard, A.S. No. A.1 [4], which contained the same requirements for the steel as the 1920 report.

Australia's first concrete structures Code [5], S.A.A. CA.2, was published in 1934, and it required bars used as reinforcement to comply with Standard A.S. No. A.1, and have a maximum working stress not exceeding 0.45 of the yield point or 124 MPa (18,000 lbs./in.^{2}). It was revised in 1937, and in 1941, a special war emergency revision was released, which saw the maximum working stress of mild steel bars increased to 138 MPa (20,000 lbs./in.^{2}) to better utilise the available steel. Other steel strengths were also included as follows:

- Mild steel – 138 MPa
- 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

Special reinforcement included a pair of round bars cold twisted together helically, while restrained, to raise the yield point of the steel. This was probably the forerunner of the square twisted bars available from 1957. The 1943 and 1947 revisions of CA.2 made the changes permanent. Without knowing if higher strength steels were used in a project during this period, and in the absence of testing, allow a maximum of 138 MPa as an allowable working stress in the reinforcement.

With continued developments in reinforcement, 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.

Concrete was mixed by proportion, which was left to the engineer to define. Machine mixing was recommended in the 1937 Concrete Structures Code CA.2, thus improving the uniformity of mixing, and hand mixing was only to be used when specially approved in writing. Concrete was to be adequately compacted by puddling (rodding) with suitable tools as no vibrators existed at the time (**Figure 5 - right**). Curing was recognised as the concrete had to be kept moist for at least seven days. Concrete strengths of 1,500 psi (10 MPa) up to 2,900 psi (20 MPa) were recommended, with allowable working stresses from S.A.A. CA.2 generally limited to 0.35 times f_c' for flexure and 0.225 times f_c' for compression.

4. Period from 1957 to 1963

When AS CA.2, the Australian Standard Rules for the use of Normal Reinforced Concrete in Buildings (known as the SAA Code for Concrete in Buildings) [6] was revised in 1958, a series of Australian Standards was required to cover the range of reinforcing materials required to meet the provisions of AS CA.2. This series of Australian Standards was published in 1958 as different parts of a single document, AS No. A.81, A.82, A.83, A.84 and A.92 *Steel Reinforcing Materials for Normal Reinforced Concrete* [7]. They were reprinted in 1959 and 1962 and remained current until 1965.

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 [8].

AS No. A.83 covered both single cold-twisted reinforcing bars (**Figure 7**) and twin-twisted reinforcing bars. The minimum yield stress and ultimate tensile stress of these bars were as follows:

- Single twisted bars <10 mm dia. or side – Min. yield of 483 MPa, Min. ultimate of 552 MPa
- Single twisted bars ≥10 mm dia. or side – Min. yield of 414 MPa, Min. ultimate of 483 MPa
- Twin twisted bars <10 mm dia. or side – Min. yield of 372 MPa, Min. ultimate of 434 MPa
- Twin twisted bars ≥10 mm dia. or side – Min. yield of 372 MPa, Min. ultimate of 434 MPa

The twisting of the bars provided some anchorage into the concrete, reported to be about 40 to 50% of the current ribbed pattern rolled onto the bars. This allowed for some lapping of the reinforcement (**Figure 8**), but the reduced bond strength must be allowed for when checking older structures.

Figure 7. Single and Twin-twisted square bars

Figure 8. Lapping of square twisted bars

In the preface to the 1958 revision of CA.2, it states that it was a complete revision of the 1937 edition of the SAA Code for Concrete in Building and was limited to normal reinforced concrete structures and was based on permissible stresses only. In the book *Design of Reinforced Concrete* by Cowan and Smith [9] first published in 1963, it states that the 1958 version of the Concrete Code introduced a number of new methods, notably design based on ultimate strength and design based on model analysis. It also states, that it was the first textbook written specifically for Australian concrete design Codes.

Concrete strengths in this period increased slightly and were in the range of 2,000 to 5,000 psi i.e. 13.8 MPa to 34.5MPa. Concrete strengths could be as high as 6,000 psi (41.4 MPa), but typical concrete strengths in the range of 2,500 to 3,000 psi were used for most projects.

5. Period from 1963 to 1983

The next significant change in reinforcement was the introduction of an entirely new type cold-twisted deformed bar Grade 60 (CW.60) or 60,000psi yield strength bar (**Figure 9**).

Figure 9. Cold-twisted deformed bar (CW.60) 1963

The bars satisfied AS No. A.81-1958 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 A.83-1958 Cold-Twisted Steel Reinforcing Bars, which was referenced in the 1963 revision of the Concrete in Buildings Standard CA.2 [10]. When CA.2 was revised and redesignated as AS 1480 in 1974 [11], the cold-worked bars were covered in Table 13.2.2. 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.

The bar was designated as CW (cold-worked) but commonly was shown on drawings as C or sometimes CT with the number following indicating the diameter of the bar in 1/8 of an inch. For example, a C4 bar was 4/8 of an inch in diameter, i.e. ½ inch bar (12 mm nominal) and a C10 bar was 10/8 of an inch in diameter, i.e. 1¼ inch bar (32 mm nominal bar). The designation 6 - #4 CW @ 10" would mean six, number 4 size (or ½ inch) deformed CW.60 bars laid at 10 inch centres. Often the # symbol for number would be omitted.

The suite of Standards covering reinforcement, AS No. A.81, A.82, A.83, A.84 and A.92 introduced in 1958 were replaced with AS 1302 [12] released in 1973.

CA2-1963 allowed design based on permissible stresses (working strength design) but also allowed ultimate strength design in Appendix A of the Code. This method of ultimate strength design was restricted to concrete which was specified on the strength basis. It is unlikely that many buildings would have been designed using ultimate strength method in this period. The Concrete Code allowed concrete up to 3,000 psi (20.6 MPa) to be specified by proportions which were set out in the Code. Above 3,000 psi, strength testing was required to show that the design strength could be achieved for the proposed mix designs. The minimum strength of normal reinforced concrete was 1,800 psi (12.4 MPa).

Regarding reinforcing bars, Clause 2.4 of CA.2 in 1963 noted that 'Structural grade plain steel bars to AS A.81 are identical with similar bars to AS A149, Mild Steel for General Structural Purposes'. As such, in Clause 2.4.3 it requires that '*In the absence of reasonable assurance, such as a manufacturer's certificate, the quality of the steel shall be established by test*'. This highlights the importance of testing to establish the properties of some older reinforcing bars.

A new version of the concrete Code CA.2 was published in 1973 [13], still in imperial units. CA.2 was revised, converted to metric units and redesignated as AS 1480 in 1974 [11], which saw the introduction of the limit state design approach. For the first time, it introduced the capacity reduction factors, Ø, for ultimate strength design. It also had seven preferred concrete strengths in the range of 15 to 50 MPa with steel grades being 230S and 410C.

Also, AS 1480 included for the first time in Australian Concrete Codes a new section on simplified procedures for slenderness effects including members where the relative lateral displacement of the ends was not prevented, i.e. sway frames. AS 1480 was amended in March 1975 and reprinted incorporating amendments in 1975. It was revised again in 1982.

In 1971, a second edition of the Australian Standard A64-1971 Ready Mixed Concrete was published [14], and it was extensively revised from the first edition. By now the materials for concrete were being batched by weight, and many of the prescriptive rules relating to mixers and agitators were removed from the Concrete Code. In 1973, A64-1971 was revised and redesignated AS 1379-1973 [15] Concrete Supply. AS A64 was subsequently withdrawn in 1976.

6. Period from 1983 to Present

In 1983, Smorgon Steel commissioned the electric arc furnace in Laverton, Melbourne and the rolling mill was commissioned in the following year. In response to Smorgon's electric arc furnace, BHP commissioned a Mini Mill in Rooty Hill, Sydney in 1992. Through industry consolidation in this period OneSteel acquired and re-branded Smorgon Steel Reinforcing as the Australian Reinforcing Company (ARC) in recognition of the long heritage of quality reinforcement manufacture in Australia.

In 2017, OneSteel was acquired by the UK based Liberty Group and is now known as Liberty Steel. Liberty Steel continues to manufacture quality Australian reinforcement at both the original 1920 Sunshine facility (Melbourne), as well as the Mini Mill at Rooty Hill, Sydney.

In 1983, BHP developed a hot-rolled deformed bar known as TEMPCORE (**Figure 10**), 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 **Figure 11**. 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.

Figure 10. TEMPCORE 12 to 36 deformed bar, 1983

Figure 11. Welbend™ 410Y deformed bar with longitudinal bead

With the introduction of the hot-rolled deformed 400Y bars in AS 3600 in 1988 [16], 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.

Two further Standards covering reinforcing products for concrete were released in 1991, AS 1303 [17] and 1304 [18]. The current Standard covering reinforcing products, AS/NZS 4671 [19] was released in 2001. 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 mid to late 1990s and are covered by AS/NZS 4671-2001. 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.

The 1994 revision of AS 3600 represented the culmination of the advance from permissible stress design to full limit state design. AS 3600 was further revised 2001, 2009 and 2018. A new edition of AS/NZS 4671 is expected to be published late 2019.

7. Testing

If identification of the bar type is not possible, a sample of bar should be retrieved from the structure under consideration and tested to determine its mechanical properties. If welding is required, the chemical composition of the steel should be determined. Exposing the reinforcement may also provide the opportunity of visually assessing the reinforcement for evidence of corrosion and loss of volume of steel.

8. Splicing to Historical Reinforcement

Unlike the modern reinforcement steels, early 20th century reinforcements must be unmistakably identified or metallurgical testing performed prior to any splicing of the reinforcement by welding. Weldability is very doubtful with generally high carbon equivalent values. For example Hard Grade deformed reinforcement available in the 1960s in NSW (but unusual elsewhere) is not weldable.

From 1963 the cold worked deformed CW.60 reinforcing bars were designed to be weldable although 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.** From 1983 all reinforcement was reported as weldable. For joining reinforcement prior to 1963 with unknown chemical properties modern coupler systems may prove a more suitable alternative to welding.

9. Designation of Reinforcement

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

S…………Structural-grade deformed bars to AS A92 and A97
R…………Structural-grade plain round bars to AS A81
H…………Hard-grade deformed bars to AS A92 and A97
C or **#C**…..Cold-worked deformed bars to AS A83 and A97
T or **W**…...may have been added if the bars were twisted
ST ……….Square twisted bars (also shown as a capital 'T' with small 's' overlaid)
F…………Hard-drawn wire reinforcing fabric to AS A84
W…………Hard-drawn wire to AS A82 (today designated by **L**)

10. Conclusions

When assessing the capacity of older reinforced concrete structures the new SRIA Guide will provide guidance in the determination of what might be the appropriate design properties of reinforcement in older buildings by capturing important information about our industry and consolidating this into a single, comprehensive reference document. It will also assist with areas such as material variability, design theory (working stress or Limit State Design), reinforcement detailing and concrete strength. Existing drawings and/or project documentation will also assist in this process. Suggested yield strengths for assessment:

- **1895 to 1920:** If the proprietary system cannot be established use 200 MPa unless samples tested; Fabric (eg Imported by B.R.C.) 380 MPa.
- **1920 to 1957:** For locally manufactured reinforcing Hot-rolled plain steel bars assume 200 MPa unless samples tested. A.R.C.. If proprietary system cannot be established use 200 MPa unless samples tested. Fabric 380 MPa.
- **1957 to 1963:** Square Twisted Bar, 410 MPa; Hot-rolled plain steel bars, 200 MPa; Fabric 450 MPa.
- **1963 to 1983:** Square Twisted or CW.60 Bar, 410 MPa; Hot-rolled plain steel bars Pre 1965, 200 MPa and Post 1965, 230 MPa; Fabric 450 MPa.
- **1983 to 2001:** Hot-rolled plain round Pre 1988, 230 MPa and Post 1988, 250 MPa, Deformed 410 MPa (1983-1988) then 400 MPa (1988-2001), Fabric Pre 1995, 450 MPa and Post 1995, 500 MPa.
- **2001 to Present:** Both steel reinforcing bar and mesh, 500 MPa.

- **Unidentifiable reinforcement:** If the structure was constructed during a period when several different types of bar reinforcement were available in the market or the material is unknown, the only option could be to test several different samples of the reinforcement or assume a yield strength of 200 MPa prior to 1965, 230 MPa between 1965 to 1988 and 250 MPa after 1988.

11. Acknowledgement

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    - *c.* A.S No. A.83 – 1958 *Cold-Twisted Steel Reinforcing Bars*
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