POWER AND WATER AUTHORITY

STANDARDS BRANCH
– Power Division

PAGE	:	1 OF 7
DATE	:	2/6/88
REVISION	:	0
DISTRIBUTION	:	VOLUME 1 HOLDERS
PREPARED BY	:	G. McKINNON
AUTHORISED BY	:	BRIAN KENT

STANDARDS BULLETIN No. : S1-024

SUBJECT: CONCRETE STRUCTURES CODE

The enclosed Technical Policy No 1 draws to the attention of designers and fabricators some undesirable practices brought about by misinterpretation of the concrete structures code AS1480-1982.

This Technical Policy Note No 1 refers to the now superseded Standard AS1480, but the information is still relavent to the new concrete structures Code AS3600-1988.

Please note that this information relates to bending and welding of reinforcing bar,and therefore, to ensure that the use of steel reinforcing within our organization is in accordance with this T.P.N., the recommendation described should be adhered to.

BKent

BRIAN KENT
STANDARDS MANAGER POWER

STEEL REINFORCEMENT PROMOTION GROUP

Yorry. How does this affect our rag bolts

Level 7
41-47 Currie Street
ADELAIDE 5000

Telephone - 2126700
Telex AA82206
Facsimile 08 - 2117501

All Correspondence
C/- B.H.P.
G.P.O. Box 1818
ADELAIDE S.A. 5001

KRL:VFP
SRPGLETS DISK 2 P1

14th April, 1988

Dear Sir,

I am writing on behalf of the Steel Reinforcement Promotion Group (SRPG) who are a body consisting of steel producers, reinforcing bar and mesh manufacturers and the Cement & Concrete Association (C&CA), who are interested in the efficient and effective use of steel reinforcement in concrete.

The SRPG is concerned at the continued occurrence of incorrect and undesirable practices in relation to the bending and/or welding of reinforcing bar within the building and construction industry.

Your attention is drawn to the recently published Australian Standard 3600-1988 Concrete Structures Code and in particular, clause 19.2 of that Standard which covers material and construction requirements for reinforcing steel. It is suggested that the provisions of this clause be read in conjunction with our Technical Policy Note 1 (TPN 1), a copy of which is attached for your information. It should be noted that although TPN 1 refers to the now superseded standard AS1480, the information contained therein is still relevant and is similar to that contained in AS3600-1988. Indeed the information in TPN 1 describes in more depth the bending of reinforcing bar than the relevant clause in AS3600 (Clause 19.2.3).

We strongly recommend that the minimum pin diameter as outlined in TPN 1 Policy 2 should be adhered to without exception.

We hope you find this note of some guidance in your future workings with reinforcements and if you have any questions regarding any of the above, please do not hesitate to contact our association.

Yours faithfully,

RECEIVED
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PAWA

Ken Lewsey
SECRETARY

SRPG Steel Reinforcement Promotion Group

TPN

SRPG Steel Reinforcement Promotion Group

Technical Policy Note No. 1© TPN 1 Dec. 1986

Bending, Welding and Coating Steel Reinforcement to assure compliance with AS1480-1982

This Technical Policy Note draws to the attention of designers some undesirable practices brought about by misinterpretation of the Concrete Structures Code, AS1480-1982. (Ref. 2)

Changes to Types and Grades of Steel Bars

When AS1480-1974 (Ref.1) was being prepared in the late 1960's and early 1970's, the following steels were assumed to be available:

- Grade 410C Cold-worked deformed bars of high yield strength, including CW.60.
- Grade 230S Structural grade, hot-rolled deformed bars.
- Grade 230R Structural grade, hot-rolled plain round bars.

In a reprinted edition, AS1480-1982 (Ref.2) included:

- Grade 410Y Hot-rolled, deformed bars, high strength.

Since 1983, cold-worked bars have not been manufactured, and Grade 230S bars are not now used to any large extent. This paper therefore refers infrequently to these products.

The current (1986) range of steel deformed bars are therefore:

- Grade 410Y Hot-rolled mill heat-treated and tempered, TEMPCORE".(Trademark of BHP-Rod and Bar Products Division)
- Grade 410Y Hot-rolled, low carbon steel, micro-alloyed with vanadium "WELBEND 400SE". (Trademark of Smorgon Steel Division).

These bars are supplied in straight lengths and provide the major stock item for the reinforcing steel fabricators who are members of the Steel Reinforcement Promotion Group (SRPG)

However, in addition to the straight stock, a micro-alloy Y12 bar is supplied as a continuous coil by the BHP Rod and Bar Products Division. This material is a hot-rolled, deformed steel containing micro-alloying elements. as currently produced, and it complies with AS1302-1982 (Ref.3). It is not produced by the "Tempcore" process. The coiled Y12 bar is used generally for the manufacture of fitments by special machines which straighten the bar, bend it to shape automatically and finally cut off the finished product. Note that the coil is straightened before bending. The coil diameter ranges from 300mm (25d) to 900mm (75d).

TABLE 1.

AUSTRALIAN BAR TYPES	
Description	Size Range
1. Mill heat-treated and tempered deformed bar (straight), 410Y	Y12 to Y36
2. Micro-alloyed deformed bar (straight) 410Y	Y12 to Y36
3. Micro-alloyed deformed bar (coil) 410Y	Y12 only
4. Plain steel wire (coils) 450W	W4 to W12.5
5. Plain round rod (coils) 230R	R6 and R10 usually
6. Plain round bar (straight), 230R	R12 to R36 in selected sizes only

Note: Plain round bars are generally supplied cut-to-length as dowel bars. Rod and wire in coils is used for fitments, and the latter for fabric manufacture also.

The purpose of the above information is to advise users that there are several types of reinforcement, each with their own peculiarities, as will be described later.

Reinforcement Fabrication

The fabricator members of SRPG supply reinforcement to a building site cut to length, bent to fit within the encompassing concrete surfaces and labelled for identification purposes.

Cutting reinforcement does not cause problems. Even if cut by oxy acetylene equipment, the effect of strength loss or bond loss is zero.

Bending can have a considerable detrimental effect on the strength and ductility of the steel, and requires careful attention by the design engineer whenever standard practice is ignored or overridden

Unfortunately, the requirements of AS1480-1974 (Ref. 1) and AS1480-1982 (Ref. 2) do not reflect the fact that the steels now available (1986) are not the same as those prior to 1983. (Ref. 3).

Bending techniques requiring attention

Reinforcement should be bent by powered bending machines which permit a uniform application of force to bend the bar around a central pin of adequate diameter.

AS1480 refers to "the internal diameter of a bend" in Section 6 and elsewhere. This value is translated by fabricators into a "bending pin (or former)" of the same diameter so that the "springback" at the bend will give a larger internal diameter than the pin diameter.

Clause "6.3.2, Bends" in AS1480 specifies in paragraph (c) that the internal diameter of the bend must not be less than that specified for the bend test in the steel bar standard AS1302 (Ref.3), the wire standard AS1303 (Ref 4) or fabric standard AS1304 (Ref. 5).

The Steel Reinforcement Promotion Group is a national non-profit organisation sponsored by the reinforcing steel industry in Australia to promote the use of steel reinforcement in concrete structures, houses and pavements. Since the information it provides is intended for guidance only, it in no way replaces the services of professional consultants on particular projects, and no legal liability can be accepted by the Group for its use.

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Notes: Paragraph (a) is similar to AS1480 Clauses 6.3.2(a) and 6.3.2(d). It represents the present satisfactory situation for the majority of design situations.

Paragraph (b) is the correct interpretation of AS1480 Clause 6.3.2(c). The values are at or above the bend test.

Paragraph (c) instructs designers to specify, on drawings, bars which they expect will require straightening or rebending at a later time (e.g. in slipformed walls). Bends smaller than these will probably be the cause of a failure.

Paragraph (d) follows the advice given in CIA Current Practice Note No.17, Section 2.2 (Ref.8). These sizes may prevent damage to pre-galvanised bars and should limit strain-ageing when bars are bent before galvanising. Epoxy coating has been included because surface damage must be eliminated as far as possible, but no guarantee is offered that these pins are adequate To some extent (d) replaces AS1480 Clause 6.4 (g).

Policy 3. Hooks and Cog for end anchorage

A hook or cog used for end anchorage means a bend having an internal diameter complying with Policy 2(a) to (d) as appropriate, and:

(i) for a 180-degree hook — a straight extension beyond the bend of 4 d but not less than 65mm

(ii) for a 135-degree hook or a 90-degree cog — requiring the same total length as provided by a 180-degree hook with the same pin size.

Note: These definitions are similar to AS1480 Clause 6.3.1, but draw designers' attention to the variable hook and cog allowances required by Policy 2. Note the inclusion of a 135-degree hook with fitments.

Table "Policy 3" gives hook and cog length allowances.

Policy 4. Welding of Reinforcing Steel

Welding of reinforcing steel must comply with AS1554, Part 3 (Ref. 6), from which come the following selected extracts as they relate to this practice sheet.

Clause 1.6 **WELDING OF REINFORCING STEEL**

1.6.1. **Approval and Type of Welding.** Welding of reinforcing steel shall not be carried out unless it is shown on the drawings, or in other appropriate documents, or is otherwise approved.

Welding of reinforcing steel shall comply with the requirements of this standard, AS1554, Part 3.

1.6.2 **Limitations on Welding.** The following limitations on welding shall apply:

(a) Where tack welds are not shown on the drawings but are required to maintain the reinforcing steel in its correct position, only approved tack welds that comply with the requirements of Clause 3.4 (of AS1554, Part 3) shall be made.

(b) Except where tack welding of main bars into the corner of fitments is approved, welding shall not be carried out within 75mm of any bent portion of a bar which has or had a bend of internal radius less than 8 times the bar size.

1.6.3 **Welding Different Grades of Reinforcing Steels.** It shall be permissible to weld together different grades and types of reinforcing steels provided that the appropriate requirements of this standard are complied with for each grade.

Clause 1.7 **JOINING REINFORCING STEEL TO STRUCTURES.** Where reinforcing steel is to be joined to steel plate, rolled sections or hollow sections by butt or fillet welds, the welds shall comply with the requirements for structural welding given in AS1554, Part 1.

Interconnection of precast concrete members by way of reinforcing steel projecting from the concrete may be made by fusion welds complying with this standard.

Clause 1.8 **WELDING PROCESSES.** Welding shall be performed using manual metal-arc welding, semi-automatic or automatic gas-shielded or flux cored metal-arc welding, flash butt welding, or flame pressure welding. Other welding processes may be approved following satisfactory procedure testing

Clause 3.4. **TACK WELDS.**
In subclause 1.4.13 Tack weld is the definition that it is a short weld used for assembly and fixing purposes only". A Part 3 tack weld differs from a Part 1 tack weld.

3.4.1 **Limitations on Tack Welds.** The number of tack welds shall be kept to the minimum necessary to locate the reinforcing steel during erection and placement of concrete.

Tack welds shall not substantially reduce the cross-section of the reinforcing steel nor adversely affect its strength.

3.4.2 **Size of a Tack Weld.** Tack welds shall —

(a) have a throat thickness not less than 4mm;
(b) have a length not less than the size of the smaller bar; and
(c) comply with the preheat requirements given in Table 4.7 of AS1554, Part 3.

[Note: Reference to the full standard is strongly recommended.]

References:

1. "AS1480-1974 SAA Concrete Structures Code". SAA, Sydney, N.S.W.
2. "AS1480-1982 SAA Concrete Structures Code". SAA, Sydney, N.S.W.
3. "AS1302-1982 Steel Reinforcing Bars for Concrete" Amended 1983. SAA, Sydney N.S.W.
4. "AS1303-1984 Steel Reinforcing Wire for Concrete" Amended 1986. SAA, Sydney, N.S.W.
5. "AS1304-1984 Welded Wire Reinforcing Fabric for Concrete" Amended 1986. SAA, Sydney, N.S.W.
6. "AS1554-1983 SAA Code for Welding in Building Part 3. Welding of Reinforcing Steel" SAA, Sydney, N.S.W.
7. "DR85137 Draft Australian Standard for Concrete Structures". SAA, Sydney, N.S.W.
8. "The Use of Galvanised Reinforcement in Concrete" September 1984. Concrete Institute of Australia (CIA), Sydney, N.S.W.

Who to contact: For enquiries about this publication, in the first instance contact the reinforcement fabricator for your project. Depending on the information you require, you may be referred to other members of SRPG.

Members of the Steel Reinforcement Promotion Group:

Aquila Steel Company Limited
Boral Steel Limited
Cement and Concrete Association of Australia
Humes A.R.C.
Smorgon Steel Division
The BHP Steel International Group
— Rod & Bar Products Division
— Wire Products Division

TABLE 2

MINIMUM COLD-BENDING PROPERTIES — BEND TESTS	
AS1302 for bars	AS1303 for wire & AS1304 for fabric
Bend 180 degrees	Bend and rebend. 90 deg; back 180 deg; forward 90 deg
230R on pin 2d 410Y on pin 4d	450W on pin 2d with rebend test above

Note: d is the bar diameter.

All bending implies that steel must have been strained beyond its elastic limit, or it would spring back straight.

When bends are specified by an engineer to be at or smaller than the bend-test value, the result is that the material may well be strained almost to its ultimate limit state and is then being put into the structure with expectations that it will still have an adequate factor of safety.

The only realistic applications of tight bends (say 4 bar diameters or smaller) are when —

a) the corner of a tie or stirrup requires the main steel bar to fit tightly into the bend. A pin size of 3 diameters for 230R or 450W or fabric is justifiable and has caused few problems in practice.

b) the bar is bent out of the way to facilitate formworking, as with slipform construction, except that when the bar is bent back again, failure can occur.

Under normal circumstances, SRPG members use a 5 bar-diameter pin for all Grade 410Y straight or coiled bars, and a 30mm to 40mm pin for round bar or wire up to 12.5mm size when used as fitments (ties or stirrups). This applies to each bend, including any hooks. A pin size of 4d for Grade 410Y bars is the smallest which should be used.

Causes of failure at bends

Failure of a reinforced concrete member due to overload or gross errors in design is most uncommon.

When compared to the hundreds of thousands of bends made in bars each year, the number of bend failures is quite small, but when a bar does break at a bend, the cost of rectification far outweighs the initial outlay.

Documented causes of failure at bends include:

(i) **"readjustment"** or **"minor rebending"**, often done with a sledgehammer or by putting a pipe over the bar and bending it across the sharp edges.

(ii) **"considerable rebending or straightening of a bend"** as with slipform construction. Methods vary but the use of jerky forces is a major contributor. A bend subjected to torsional forces may not have adequate resistance.

(iii) **"crushing of the deformations"**. It is obvious that when a bar is bent, the curved portion has been strained beyond the elastic limit (otherwise it would spring back to its straight condition). The amount of force needed to perform the bend will be relatively more severe as the pin size decreases in proportion to the bar size.

The bearing pressure exerted by the pin on the deformations of the bar can be so great that they are cracked or even flattened. Any rebending can overstress the weakened section inside the bend, and may even crush the deformations on the other side of the bar when the direction of the force is reversed.

Bending with a pipe over the bar is particularly destructive of deformations.

Despite claims by the steel makers that Grade 410Y bars can be bent back on themselves or bent around very small pins, the SRPG strongly opposes both practices as being an improper operation.

(iv) **"strain ageing"** of the steel. This is a complex subject and depends on the type of steel, and the amount of bending to which it has been subjected.

Strain ageing manifests itself in an increase in strength and a decrease in ductility. However cold deformation (bending) of the steel also reduces ductility so that the ductility of the steel after strain ageing is a function of the amount of prior strain plus the extent of strain ageing.

Strain ageing of steel is attributable to uncombined or free interstitial atoms such as carbon or nitrogen migrating to dislocations newly formed by cold-work (bending) and locking them.

Nitrogen is thought to be the principal element involved with ageing at ambient temperatures, while carbon becomes more mobile at higher temperatures, say over 100°C.

(v) **"age-hardening"** of the steel. This is also a complex topic and is usually associated with the tempering or subsequent heat treatment of a super-saturated solution produced by quenching and rapid cooling. The tempering results in the precipitation of a second phase.

With micro-alloyed steels, ageing at temperatures of the order of 600°C can produce a strength increase until over-ageing of the precipitates occurs with a subsequent decrease in strength.

(vi) **"bending followed by welding"**. Welding near a bend in a bar (and near a punched hole in a plate also) can cause ageing and possibly a notching effect if the technique is poor. Generally welding should not be close to a bend. Reference to AS1554 Part 3 (Ref. 6) is recommended.

(vii) **"bending followed by galvanising"**. Galvanising involves immersing steel in molten zinc at about 430°C. It has been suggested that because the rate of strain ageing occurs more rapidly at this temperature level that during the galvanising process an "oven ageing" effect may occur with some slight restoration of ductility.

(viii) **"galvanising followed by bending"**. The principal effect in this situation may be cracking of the coating, rather than bar failure at the bend position. Galvanised coatings, especially the iron rich layer at the interface, can be a relatively brittle material, although the pure zinc surface coating is quite soft. For these reasons, the pin sizes should be kept as large as possible to reduce surface strains, both inside and outside the bend.

Rebending of coated bars may destroy the coating.

(ix) **"bending bars which have been heated"**. Heating Grade 410Y bars for any reason must be controlled by the designer and the contractor.

"Tempcore" bars will lose their quenched and tempered outer layer; micro-alloyed bars such as "Welbend" lose ductility after being bent normally and then heated and straightened.

The maximum bar temperature must not exceed 450°C. This can be checked with temperature indicating crayons, available from welding material suppliers.

Steel becomes "red-hot" at about 850°C so it is obvious that any sign of reddish colour in the bar indicates the temperature is too high.

Clauses 6.4(d) and (e) of AS1480 permit bars to be heated to "cherry-red" but restricts the design strength of Grade 410C (the cold-worked bars, not the 410Y bars) to 230 MPa. Whilst this is not incorrect for steel such as Grades 230S, 230R and and 410C, this 800°C - 850°C is damaging to the crystal structure, strength and ductility of Grade 410Y steels. We therefore consider that this clause is no longer adequate and suggest an alternative later.

(x) **"lifting hooks made from reinforcing steel".**

The use of reinforcing steel as lifting hooks must be totally prohibited.

Rebar is not meant to be bent to the shapes sometimes specified in ignorance by designers.

Rebar is not intended to be subjected to the sudden impact loads associated with lifting large pieces of concrete.

The deformations on rebar are intended to act in combination with the concrete in which the steel is embedded. No engineer designing in structural steel would dream of using material with a continous array of notches along its length yet this is the case with deformed bar.

Deformed bars may be embedded in concrete and then connected to approved lifiting points by welding or other means, but using a part of the bar protruding from the concrete (say in the form of a 90 to 180-degree loop) can be a danger to life and property.

Tilt-up construction is now one of the most popular forms of wall construction — designers are well aware of the need for careful design of fixings and lifting points and always use specially designed products, not ordinary reinforcing bars.

Please be warned and take heed of this advice.

The Common Feature of Failure

In all cases, the most common feature associated with failure of reinforcing steel is the operation of bending the steel to shape or the operation of rebending, "adjusting or straightening the bar from a previously bent condition.

Similarly, the prime cause of failure is specifying an internal diameter of bend which is much too severe for the quality of steel currently available

It should be pointed out that the requirements of AS1302-1982 ensure that Australian-made reinforcing bars are the best in the world.

When specifiers ask for manufacturing techniques which are much more severe than the acceptance tests, the steel quality cannot be blamed for poor results.

The Solution

The Steel Reinforcement Promotion Group has adopted the following policies for bending reinforcing steel.

The details comply with AS1480 and of necessity will often exceed the minimum requirements set out therein.

Similar proposals have been submitted to the SAA Committee for Concrete Structures, BD/2, but until the new Unified Concrete Structures Standard (Ref. 7) is adopted, AS1480 requirements still control design and con- ction.

Policy 1. Bending in General

Reinforcement may be bent either cold or hot.

(a) Cold bending must be done by the application of a consistent force, around a circular pin of diameter complying with Policy No. 2.

(b) Hot bending shall be approved by the designer before bending and fully supervised to ensure that:

(i) the steel is heated uniformly through the section and at least 100mm each side of the portion to be bent,

(ii) the temperature does not exceed 450°C because above this temperature there can be a reduction in the strength of the steel, and

(iii) the bar is not cooled by quenching.

However, if the temperature is likely to exceed 450°C then the stress in the 410Y steel after heating should be calculated by the designer to check it will not exceed the design (yield) strength of 250 MPa.

Hot bending is regarded as an emergency operation and is not a normal process of rebar fabrication.

Grades 230S and 230R may still be heated as in AS1480-1982 to cherry-red heat.

(c) Reinforcement which has been bent and subsequently bent in the reverse direction or straightened, shall not be bent again within 20 bar diameters of the previous bend. The reason for this is to keep the two bent zones apart.

(d) Reinforcement partially embedded in concrete may be field bent provided that the bending complies with (a) or (b) above and the bond of the embedded portion is not impaired because of the bending. The circular pin around which the bend is made shall comply with Policy No. 2. A raw pipe-end shall not be used.

[Note: Policy 1 is basically Clause 6.4 of AS1480.]

Policy 2. Minimum Pin Diameters: ("Internal diameter of bends" is used by AS1480.)

The minimum pin diameter for any bend will be the largest appropriate value as follows, based on the bar size d_b —

(a) For reinforcement generally, other than fitments as in (b), or for bends defined in (c) and (d): —

(i)	All deformed bars	$5d_b$
(ii)	Fabric	$3d_b$

(b) For fitments such as stirrups, ties and ligatures made from:—

(i)	Wire and fabric	$3d_b$
(ii)	Grade 230R bars	$3d_b$
(iii)	Grades 410Y and 230S deformed bars	$4d_b$

(c) For reinforcement in which the bend is intended to be **subsequently** straightened or rebent, of :—

(i)	Size 16mm or less	$4d_b$
(ii)	Size 20mm or 24mm	$5d_b$
(iii)	Size 28mm or more	$6d_b$

Any straightening or rebending shall be clearly specified or indicated on the drawings.

(d) For reinforcement which is epoxy coated or galvanised, either before or after bending, of:–

(i)	Size 16mm or less, including fitments	$5d_b$
(ii)	Size 20mm or more	$8d_b$

TABLE POLICY 3 — HOOK AND COG ALLOWANCES

Type of Bar	Nominal Diameter of Pin	MINIMUM LENGTH OF STEEL REQUIRED TO FORM A STANDARD HOOK OR COG OF 180 degrees, 135 degrees, or 90 degrees FOR BAR SIZE d_b (mm) R6	R10	Y12	Y16	Y20	Y24	Y28	Y32	Y36
a) Normal Bends										
Fitments: Bar Grade 230R, Fabric & Wire (+)	$3d_b$	100	100	120	140	NOT RECOMMENDED HERE				
Fitments: Bar Grade 410Y	$4d_b$	110	130	140	170	200	230	270	300	340
Bars other than in fitments above, and (b) or (c) below.	$5d_b$	120	140	160	180	220	260	300	340	380
b) Bends designed to be straightened or rebent subsequently										
(i) Bar size ≤16mm	$4d_b$	110	130	140	170	NOT APPLICABLE HERE				
(ii) Bar size 20 or 24mm	$5d_b$	120*	140*	160*	180*	220	260	NOT APPLICABLE HERE		
(iii) Bar size ≥28mm	$6d_b$	130*	160*	180*	210*	240*	280	330	380	430
c) Bends in steel epoxy coated or galvanised either before or after bending										
(i) Bar size ≤16mm	$5d_b$	120	140	160	180	NOT APPLICABLE HERE				
(ii) Bar size ≥20mm	$8d_b$	140*	180*	200*	240*	290	340	390	440	500

Notes: 1. These hook length allowances may exceed the values given in AS1480-1982, Table G5. Length allowance includes a cutting tolerance of approximately 20mm.
2. * Indicates values for bars smaller than range stated, but with larger pins.
3. + Although the actual sizes of wire and bar are different, the same values should be used for W6, W10 and W12.