Reinforcement quality assurance and certification and validation aspects

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If the reinforcement in concrete is not of proper quality and/or is not accurately detailed, the performance of the structure gets affected seriously. In this paper, the authors endorse the need for strict quality assurance and control and describe the certification and validation aspects.

Steel reinforcement is routinely used in reinforced concrete (RC) structures to augment the relatively low inherent tensile strength of concrete. It is also used:

- to carry shear, compressive and torsional forces in excess of concrete capacity
- to control cracking of concrete members under working loads or as a result of early thermal effects
- to minimise or prevent spalling of concrete in fire conditions, as a result of seismic effects, or in the highly stressed regions around anchorages in prestressed concrete construction.

Reinforcement, therefore, plays a vital role in ensuring the safety, integrity and durability of almost all concrete structures. It can only perform that role satisfactorily if it:

- possesses the required physical and metallurgical properties
- is of acceptable quality
- is stored, handled, cut and bent so as to avoid damage and contamination
- is properly and accurately fixed.

In order to realise the above-referred objectives, it is very necessary that the detailing of reinforcement is meticulously carried out and that necessary detailed working drawings and bar bending schedules is made available to the field engineers. It is also necessary for the field engineers to critically scrutinise the drawings and bar bending schedules received by them for constructability. They should have a dialogue with the design engineers if required and bring to their notice any difficulties in realising the reinforcement as per the drawings and schedules. It may also be necessary at times to revise the drawings and/or schedules based on such a dialogue.

Design process

The drawings issued to the contractors need to be complete. The contractors should have the option to take the right decisions to rationalise reinforcement in order to achieve early striking of formwork and to optimise productivity.

In any project, reinforcement drawings may be revised several times as a result of technical or human error or a change to redesign initiated by one of the parties involved in the construction contract. Such changes may have implications on the speed and cost of construction. Number of revisions should be reduced since the contractors' participation minimises the element of change during execution of the project.

During the execution of a flyover project at Ludhiana, drawings for deck girders were approved and 40 girders were cast; after that the consultant revised the drawing (changing the spacing of reinforcement). The owner rejected the 40 beams already cast. This resulted in a serious set back in project completion schedule and cost overrun.

Requirements for bond

The IS code is silent regarding the bond strength of coated reinforcement bars. Any type of coating whether it is epoxy or co-polymer based concrete coating (CPCC) or Karaikudi

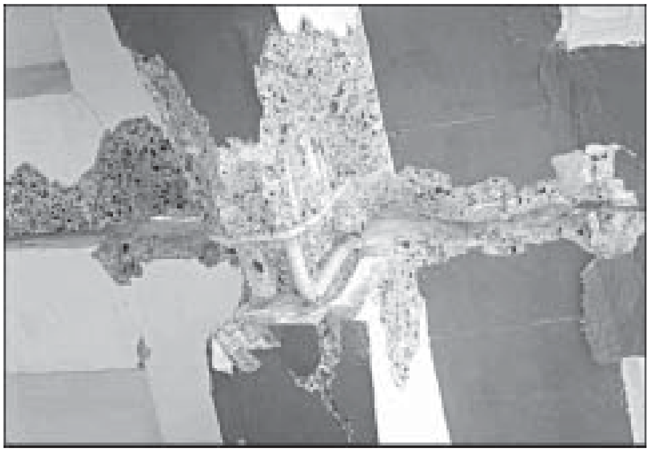


Fig 1 Surajbari Bridge, Gujrat after 2001 earthquake. (Note: no bond of concrete with epoxy coated reinforcement)

treatment, reduces the bond between reinforcement and concrete, *Fig* 1, and this is rarely taken into account by the designers. The loss of bond of coated bars may be as much as 50 percent in some cases As per *FIP Bulletin 10 – Bond of Reinforcement Concrete* – "The epoxy coating is much smoother than the normal mill scaled surface of non-coated bars and is chemically inert. Chemical addition and friction between bars and concrete are therefore reduced by coating". It is also reported that anchorage capacity of hooks and bends is reduced by coating. A 20 percent increase in the length of developmental epoxy coated bars is recommended.

Ductility requirements

The requirements are not addressed at all in IS 1786 whereas BS 4449 provides for two ductility categories 460A and 460B. As per the BS Code while the yield strength for both the categories is same, the elongation at fracture is increased to 14 percent and total elongation is increased to 5 percent in the case of 460B. As per the BS Code, the maximum carbon equivalent value is limited to 0.51.

Fig 2 Congested reinforcement (should be avoided)

Table 1: Common abbreviations used in drawings

Abbreviation	*Element*
B	Bars in bottom of slab
BB (in 2 way slab)	Bottom layer of bottom reinforcement
T	Bars in top of slab
TT (in 2 way slab)	Top layer of top reinforcement
EF	Bars in each face
NF	Bars in near face
AP	Bars alternately placed
AR	Bars alternately reversed
AS	Bars alternately staggered
UB	'U' bars
LB	'L' bars

Need for detailing

The satisfactory performance of RC structure is dependent on the accurate placement of carefully detailed reinforcements; otherwise concrete elements are marred by cracking, rust marks and similar problems directly related to workmanship. Certain defects result from poor design work, poor detailing does not permit application of satisfactory workmanship and faulty dimensioning of such critical details as location and cover to reinforcements.

Good detailing and scheduling of reinforcement helps the construction process considerably by minimising costs, delays and disputes, by easing the reinforcement fixers' task and by providing the contractor with a certain amount of flexibility both in fixing and in construction stage.

It should be appreciated that simple lines indicated in the structural drawings can be misleading. A simple line indicating a link or stirrup bar in a corbel is easy to include on the drawing board. However, a line has little thickness and to include the substantial bar of steel, bent to shape, often proves difficult and sometimes impossible.

At the ends of prestressed beams, considerable reinforcement is included to contain the bursting forces. These steel bars can be simply drawn but when translated into actual bars in three-dimensional form, extreme congestion often results, *Fig* 2. In consequence, it may prove difficult to place and compact concrete.

Many inserts are incorporated into structural concrete for fixings, fastening, bearing plates etc. There are also projecting bars and dowels for connections between precast elements or between insitu and precast concrete. These inserts must be detailed and scheduled. Omissions of any of these fixings can prove expensive.

Bar marking on drawings

The generally accepted parameters for bar identification is as follows:

- number of bars
- type of steel
- diameter of bars
- mark no of bar

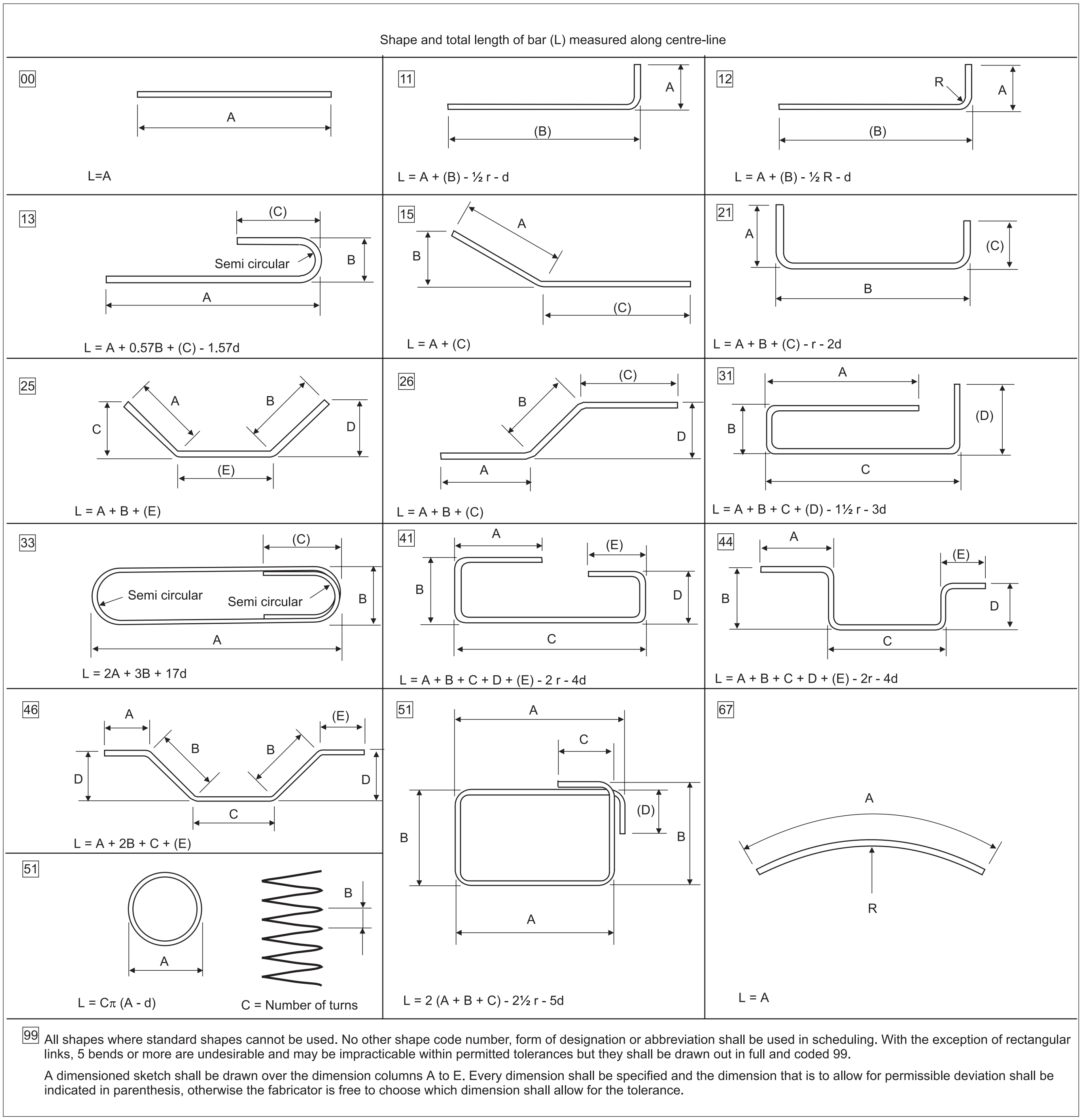


Fig 3 BS 8666 : 2000 standard shapes

- spacing of bars.

The detailer should include every information on the drawings using some of the abbreviations given in *Table* 1.

It is important is to use a standard method of detailing. The advent of computer aids in design and detailing has reduced the number of drawing errors and inconsistency between schedules and drawings. The main problems which now arise are thus where the line on the drawing misleads, radius and thickness are combined in some instances with the result that some bars cannot be fitted within the allocated space in the formwork. At column-beam junctions there is often a considerable amount of reinforcement cramped into a restricted space and the main beams and main column bars may clash.

A mechanical welded splice shall develop at least 125 percent of the specified yield strength, f_y , of the bar to ensure sufficient strength in splices so that yield can be achieved in a member and thus brittle failure avoided; the 25 percent increase above the specified yield strength was selected as both an adequate minimum for safety and practicable maximum for economy. A full welded splice is primarily intended for large bars in main members. Wherever practical, direct butt splices are preferable for larger diameter bars.

Preferred shapes of reinforcements

Though a very large number of shapes and configuration are being practised, it is desirable to limit the numbers of shapes. This is in order to reduce mistakes during fabrication and erection and also to ensure practicability in cutting, bending and installation. *Fig* 3 gives an example-preferred shape recommended by Construction Industry Research and Information Association.

Grades of reinforcement bars

The BS Code allows for the use of three grades of reinforcement bars, namely, *Fe* 415, 500 and 550. Facilities exist in the country for the manufacturers of these grades. However, *Fe* 415 is the most predominantly used grade in India. The consultants limit specification to only *Fe* 415 grade due to unproven prejudice against higher grades in terms of ductility. Consequently, congestion of reinforcement in many industrial structures is very common leading to deficiencies in the quality of the structure. On many occasions it is just not practical to satisfactorily place and compact the concrete with heavily congested reinforcement. This is evident from large number of cases where problems have been reported during the construction of thermal power stations, atomic power stations, etc. Grade *Fe* 415 is already obsolete in the developed world. The minimum grade as per BS: 4449 is *Fe* 460.

Recommended diameters for reinforcement

The IS specification (IS 1786) specifies nominal sizes of 4,5,6,7,8,10,12,16, 18, 20, 22, 25, 28, 32, 36, 49, 45 and 50 mm bars. The reasons for specifying such a large number (18) of nominal sizes are not clear. In practice many of the sizes are neither being rolled nor being used. On the other hand, it gives an opportunity for the consultants/designers to specify odd sizes such as 18, 22 mm etc and create consequent difficulties during execution both due to non-availability of odd diameters in the market and in terms of quality assurance. It is not possible to distinguish between 20 and 22 mm diameters or 18 and 20 mm diameters by visual examination. Mistakes are bound to happen.

The European practice recommends only the following diameters: 8-10-12-16-20-25-32-40-50 mm

These diameters have the great advantage of being distinguishable with naked eyes. The section of each bar corresponds to approximately the sum of the sections of the two preceding lower diameter bars which provides for and theoretically facilitate all combinations. The CEB model code recommends bar diameters of 32 mm or lower. Generally larger diameters are not recommended to be used for obvious quality reasons.

The Indian standard code of IS 1786 was last revised in 1985 and in the context of world wide developments, the code needs immediate revision.

Weldability

IS 1786 – Clause 0.2 (Foreword) states that "there is also need for these steel bars to be welded and fabricated on the site easily. For this, strength and ductility had to be achieved at the lowest possible carbon content". However, the requirement of welding is not specifically dealt with in IS 1786. The corresponding British Standard BS 4449 : 1997 specifies the requirements for weldable steel bars in terms of carbon equivalent value. In the absence of such specifications in IS 1786, quality problems do frequently arrive when welding is resorted to.

Chemical composition

The IS code permits carbon content 0.3 percent whereas the internationally accepted maximum value is only 0.25 percent. The increased permissible carbon content has been responsible for corrosion of reinforcement steel in the large number of cases.

Tolerances on dimensions and nominal mass

IS 1786 Clause 6.2 (*Table* 2) provides tolerances and nominal mass of ± 8 percent for bars upto and including 10 mm, ± 6 percent for bars upto 12 to 16 mm diameter and ± 4 percent for bars over 16 mm diameter. These are very liberal in the international context and the manufacturers take full advantage by supplying bars upto the specified tolerances . By the very nature of rolling process, the bars generally have plus tolerances. The bars are supplied by weight but the design and construction is based on the specific theoretical bar diameters and in the bargain the project cost goes up. In major projects the loss runs to several million rupees per annum which of course is reflected in higher project costs.

Decoiled material

The processor should operate a documented procedure which assures that the decoiled material continues to meet the mechanical property requirements of the IS (EN 10080).

This procedure should include the following:

(i) visual inspection of every coil processed. For ribbed steel, a rib height or indentation depth measurement on at least one sample per day and/or at each size change.

(ii) sampling and testing of the decoiled product at a frequency of one sample per diameter and machine per week.

Bending schedules for reinforcement

Shapes and dimensions of bars cannot in general be deduced from the reinforcement drawings in isolation. The main function of the bending schedule is to define exactly the shape of each bar within a group of bars having the same bar mark. A standard layout of the bar bending schedule is given in IS 2502. Schedule normally contains information concerning weights of reinforcement.

It is the responsibility of the design team to prepare the bar bending schedules. IS 456 also stipulates that bar bending schedules shall be prepared for all reinforcement work (Clause 12.1) No schedule should cover more than one drawing. Many organisations follow the very good practice of including the bar bending schedule on each structural drawing.

Role of field staff

Discussion between the field staff and the designers/detailer early can result in simplification of reinforcement details and introduction of joints in bars at points in the structure which best suit the eventual location of the construction joints, determined by casting method.

Where the work is of a complex nature, the supervisor should press for adoption of open stirrups and links, which allow ease in adjustments of cages to maintain the required cover.

The supervisor should pay special attention to the following:

- *(i)* where, for construction requirements, bars have been diverted, bent into and allowing formed face or for later insertion, failure to ensure that these bars are properly rebent can have serious consequences.
- *(ii)* where openings are formed in a slab, possibly in accordance with the revised detail, it is important to ensure that additional bars required to trim the openings are installed as detailed – a point which may easily be overlooked in the course of changing or inserting formers into the formwork.

The field staff should carry out the following checks:

- *(i)* check fixability of the detailed reinforcement and effect on construction sequence.
- *(ii)* check drawings and schedules for errors and inconsistencies.
- *(iii)* check bar bending schedule
- *(iv)* answer queries from steel fixers and resolve problems, in consultation with the designer, if necessary.

Check fixed reinforcement before starting to place concrete.

Spacers for reinforced concrete

The inadequate use of spacers and chairs has been a major cause of variations in cover to reinforcement and consequently decreased durability of concrete. Unfortunately, there is no comprehensive national standard for the use or the performance of spacers and chairs. IS 456 : 2000 merely states that "all reinforcement shall be

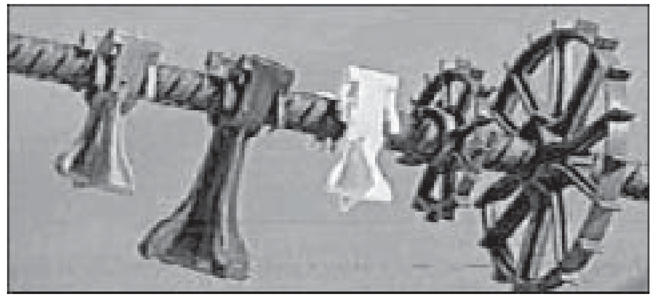


Fig 4 PVC spacers of different types

placed and maintained in the position shown in the drawings by providing proper cover blocks, spacers, supporting bars etc". (Clause 12.2). While this is a specification requirement, there are no guidelines in this regard either in the IS codes or in the technical specifications.

The spacers are generally called cover blocks in India. There are no specific guidelines for the cover blocks. In practice, cover is maintained by a variety of crude contraptions ranging from pieces of broken tiles or broken stones or timber to mortar blocks. None of these are really satisfactory. They do not maintain the cover except perhaps the mortar block, which again is not satisfactory because of the porosity. Porous blocks result in premature corrosion to reinforcement. Occasionally, some specifications do call for cover blocks of concrete of the same grade as that of concrete. While this may be satisfactory, its application is limited to upper end of the cover, say more than 50 mm. There is also no guarantee that site-made concrete cover blocks are of the same quality as that of the concrete. After all, hardly any constructor would be using concrete from batching plants for manufacturing of cover blocks.

Considering the above, the specifications of developed countries do not permit any of the above contraptions including site-made concrete cover blocks. The standard practice elsewhere is to provide PVC spacers or cover blocks, *Fig* 4. Two main types are available – clip-on where the clip action is an integral part of the design of the spacer and wire-on where the spacers are attached to the bar by the use of binding wire. These are manufactured in factory and provide cover up to 100 mm and 5 mm increments. Sizes commonly available are 20,25,30,35,45,50,60 and 75 mm.

PVC cover blocks

These blocks are lightweight, non-porous and chemically inert in concrete. The PVC cover blocks should have rounded seating such that holes are not punched in the formwork and do not deform under load nor should they shatter or severely crack. The PVC cover block will not rust thus eliminating blemishes on the surface of the concrete.

PVC cover blocks are being manufactured in India, but their use is very limited. Many of the consultants/supervising engineers do not permit the use of PVC cover blocks, perhaps because of the lack of familiarity. This is an excellent recommended material for use as spacers. IS 456 : 2000 states that "spacers, cover blocks should be of concrete of same strength or PVC". It is also specified that the spacers or

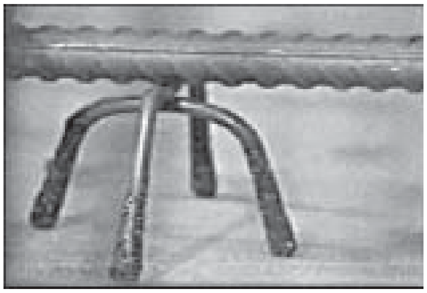


Fig 5 Reinforcement chair

chairs should be placed at a maximum spacing of one metre and closer spacing may sometime be necessary.

In USA, the most widely used spacers are factory-made wire bar supports, which are made of plain wire or stainless steel wire. The lower portions are provided with special rust protection by a plastic cover or by being made in whole or part stainless steel wires. Precast concrete blocks are used to support bars in footings, slabs on grade and as side formed spacers. Plastic supports are generally used as side formed spacers and on horizontal work.

Chairs

Chairs are manufactured from reinforcement bars to provide cover in excess of 75 mm. They are commonly used to support top horizontal reinforcement or to support vertical reinforcement in walls, *Fig* 5. They may be individual or continuous. Where placed on formwork or mud mat the legs of chairs should be provided with protection gaps. Individual chairs are manufactured in standard heights of between 75 and 300 mm and are used to support reinforcement at one point. Continuous chairs provide a straight line of support at a uniformed height. Chairs above a height of 300 mm are normally scheduled as part of the bar bending schedule.

Guidelines for tying reinforcement

There are six common ways of tying reinforcement bars, *Fig* 6.

Slabs and walls

Perimeter bar should be tied at every intersection; for bars up to and including 20 mm, alternate intersection should be tied. For bars of 25 mm or larger diameter, they may be tied at greater centres.

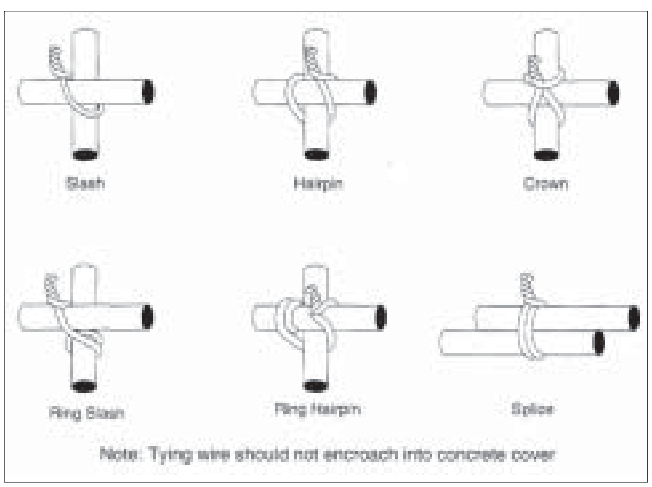


Fig 6 Six common ways of tying reinforcement bars

Cantilevers

Top reinforcement in cantilevers should generally be located by the use of chairs.

Beams

Every intersections of a corner of a link with longitudinal main bar should be tied. Other bars within the links should be tied at 50*D* centres.

Spacers within the beams

Spacers within the beams should be at centres not exceeding one metre along the beam. Spacers should be fixed on three sides of the same link.

Columns

Every intersection between vertical bars and links should be tied.

Binding wire

The binding wire is normally a black annealed wire, of 16 gauge. However, at many projects, thinner binding wire (18 – 20 gauge) are used but are not desirable. Care should be taken to ensure that the projecting ends of the binding wire do not encroach into the concrete cover. This is best achieved by turning the projecting ends inwards by lying.

Bar bending machines

Partially automated machines are now in use, *Fig* 7. Once set, bending machines produces reasonably accurate bars, but the first one or two bars of each batch are taken as a sample for checking the set and are always scrapped, increasing the wastage. This should not occur if the new automated machines are used.

Fabricators should automate information transfer in their plant. With new generation of equipment, it is possible to transfer bending schedule data from detailers computers directly to cutting and bar bending machines. This feature needs to be fully exploited.

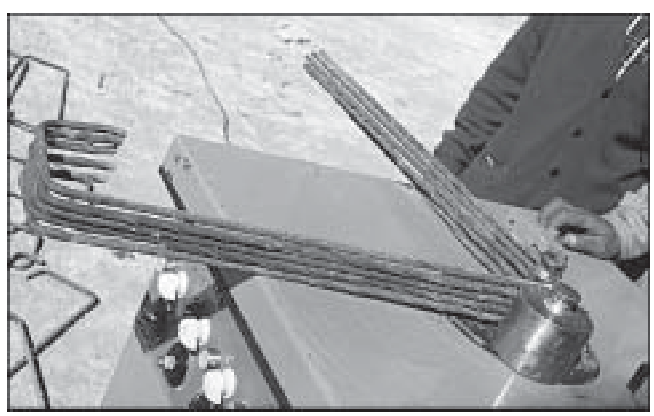


Fig 7 Bar bending machine at work

Quality assurance (QA)

An important feature of the quality management system is to ensure that the purchased or specified material complies with quality requirements. It is customary to accept that material from a source, which is working to a recognised quality assurance scheme, and fully certified satisfies this requirement without the need for further inspection and testing.

Responsibility for quality remains exclusively with the

- steel maker — for production of reinforcement steel
- fabricator — for fabrication of the reinforcement
- contractor — for handling and placing of the reinforcement in the formwork
- with the supplier — for joints and devices

Sampling inspection system (SIS)

In all cases when a producer intends to deliver material not covered by the certification scheme the SIS can be applied. The system should give at least the same quality level as control system. The tests included in SIS should generally be performed before the material is delivered (because rejection of a product already delivered to one or more location is extremely difficult).

Guidelines inspection of handling of reinforcement

It is logical that within the inspection guidelines only those properties of the component of the reinforcement are controlled which have been influenced by the handling procedure.

Special recommendations are necessary for straightening of coils, welding procedures, anchoring systems and joints, rebending of rebars.

The inspection shall be ordered not from the manufacturer but from the purchaser, who may be a distributor (usually a steel merchant) or a building contractor. The purchaser is responsible for the measures in case of non-compliance.

Random sampling shall be carried out either at the manufacturers or at the stores of the purchaser.

The specimens from the sampling units shall be submitted to an authorised test house

The test house shall submit a report to the inspector who assesses the results with reference to the relevant properties according to the rules given here and he shall decide between acceptance and rejection.

The inspector shall draw up and sign a sampling inspection report for all the test results.

Cases of serious shortcomings must be reported by the inspector to the certificating body.

Sampling

The sampling shall be made either at the manufacturer's or at the storage premises of the purchaser. Only in exceptional cases it may be performed at the building site.

Third party certification

The third party certification is designed to meet the consistency of raw materials and cut and bent reinforcement ensuring that at all stages the materials consistently meets with the requirement of the relevant standards or specifications allowing reduction in costly and time consuming site testing. The certification rules also provides for full traceability of material from the hot metal through to the construction site. Certification rules allow the use of electronic systems throughout the approval supply chain starting from material ordering, production and supply.

The certification of a product is a guarantee, granted by a recognised authority, that the product satisfies a certain number of characteristics, specified either by the approving organisation, or by the producer. The guarantee, checked both by the producer and by the organisation, avoids important and costly tests having to be carried out again in each case in which the product is applied and enables a limited check, generally only on identification, to be carried out. The official organisations therefore have an obvious interest in enforcing the use of approved products.

The approval documents summarise and explain the different headings considered below.

(i) Object of the guarantee

(ii) Identification

- name of the producer, description of the steel
- shape of the steel (drawing or photograph)
- mill's rolling mark
- quality remarks

(iii) Requirements to be checked by the producer's quality control

- tolerances on diameter and sections
- geometrical dimensions of the section with minimum values or guaranteed tolerance limits (height, longitudinal spacing and length of ribs)
- guaranteed yield point
- tensile strength
- elongation at fracture
- bending, rebending capacity

The key products covered by a typical certification scheme are:

- steel production and billet casting
- reinforcing bar
- fabric
- cut and bent reinforcement
- fabrication and welding of reinforcement

- steel fixing on site.

The comprehensive nature of the certification scheme ensures that reinforcing steel consistently satisfies the requirements of the product standard and is fully traceable from start to finish.

All the certified material is labelled and supplied with the necessary electronic or paper documentation to enable the products to be traced. The comprehensive testing and full product traceability required by certification obviates the need for the end-user to undertake any further verification tests.

Failure to specify certification approval places the onus on the purchaser to verify that material complies with the standard. This requires extensive additional product testing with significant costs and potential site delays.

Checklist for initial scrutiny of drawings and schedules

The following queries can be used as a checklist for initial scrutiny of drawings and schedules.

- Can the reinforcement as detailed be fixed?
- Does the detailing permit sensible location of construction joints?
- Is the reinforcement congested?
- Would alternative detailing provide greater flexibility or ease of fixing?
- Is there scope for prefabrication?
- What is the best sequence?
- Is the reinforcement detailed to provide sufficient rigidity and stability of cages during fixing?
- Are set-up bars, bracing bars, chairs, spacers etc required?
- Do schedule agree with drawings?
- Does reinforcement in one member clash with that in an adjacent member?
- Are scheduled bending dimensions compatible with member dimensions and specified concrete cover?
- Are starter bars detailed?

Delivery checklist

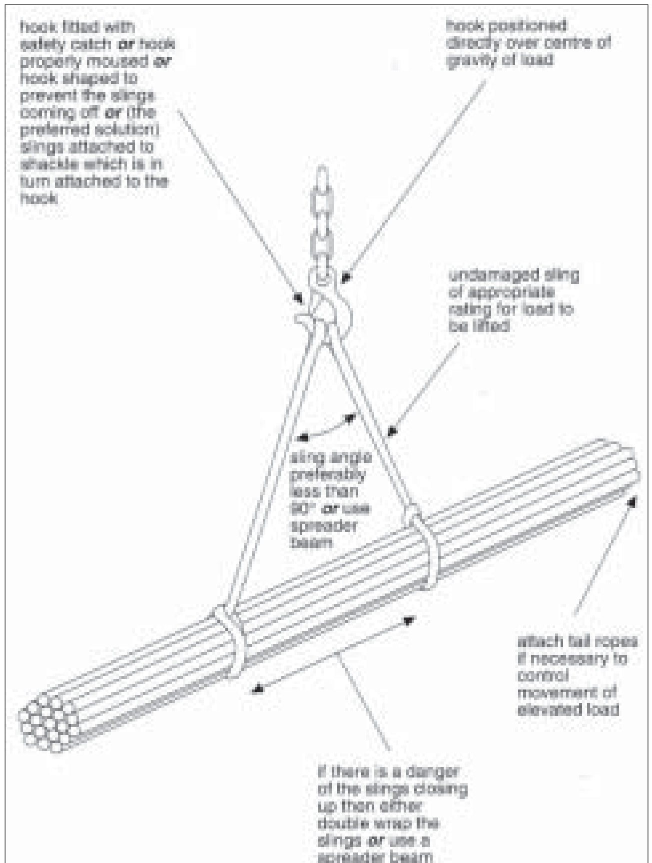
For the delivery checklist, one has to:

- ensure adequate offloading space
- check weights given on delivery ticket (by calculation and bar count)
- ensure correct handling during unloading
- check reinforcement is of correct type
- check bundles are correctly labelled
- check reinforcement is of correct grade
- check bar size (for example, by gauge or tape)
- check extend of scale and pitting.

Storage checklist

For the storage checklist, one has to:

- ensure storage area is spacious and well organised



NB: All loads must be slung by a trained slinger

Fig 8 Slinging reinforcement

- ensure reinforcement is stored clear of the ground
- keep reinforcement free of mud, oil, grease
- provide a loose protective cover over the reinforcement
- ensure good air circulation around the steel
- store materials according to construction program
- avoid long term storage of reinforcement on site.

Bending checklist

For the bending checklist, one has to:

- use a steel tape when marking bars for bending
- a site bending yard must be properly planned and set up
- reinforcement should be bent cold on a proper powered bending machine
- do not permit high yield steel to be heated on site before bending
- check the bent shape for dimensional accuracy (for example, against a full size template), bend radii and for signs of fracture.

Pre-concreting checklist

For the pre-concreting checklist, one has to:

- ensure correct number of bars have been fixed

- check that all laps are of the correct length
- ensure correct use of cover blocks, spacers etc
- check cover to reinforcement is correct at all locations
- ensure that all twisted ends of ties are bent inwards away from concrete faces
- ensure adequate access for concrete compaction.

Site actions influence costs

Certain activities control the cost incurred. Such activities include:

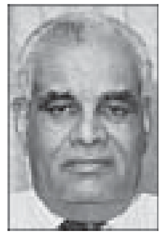
- ordering in good time in economic loads
- minimising damage by careful handling and storage
- minimising wastage by intelligent cutting and accurate bending
- minimising loss by providing secure storage
- accuracy in cutting and bending
- slinging of reinforcement must be done carefully, *Fig* 8
- prefabrication, either on or off site
- storing reinforcement in reverse sequence to use to avoid double handling
- avoidance of site welding reduces costs.

Acknowledgement

The authors have tried to focus on some desirable practices in respect of engineers' drawings, bar bending schedules and field practices. In the process the authors have freely drawn on their own experiences as well as from the following publications:

References

1. ______*Indian standard code of practice for plain and reinforced concrete*, IS 456 : 2000, Bureau of Indian Standards, New Delhi.
2. CIRIA Special Publication 118.
3. Concrete Society, U.K. Report CS – 101 (Spacers).
4. ACI Manual of Concrete Practices Part III.
5. ______*ACI building code requirements for structural concrete*, ACI 318-02.



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