Chapter 7

Reinforcement

7.1 Introduction

The expenses for materials and wages for reinforcement in concrete constructions are affected by a number of factors:

- The construction type
- The type of reinforcement-
- The amount of reinforcement
- The layout/design of the reinforcement
- The degree of prefabrication.

The costs vary from project to project, but constitute approximately 15-30 % of the total costs for a normal slack-reinforced concrete construction. The distribution between the costs for materials and wages is similarly affected by a number of factors, but in most cases they are approximately equal. In order to reduce the wage costs, it is possible to do as much as possible to make the reinforcement work production-benign already during the design phase. The reinforcement work during the production phase should, therefore, be planned and organized precisely.

7.2 Reinforcement steel

Table 7.01 shows a number of ordinarily available qualities of reinforcement steel, as well as technical data. The group designation a, b1, b3 and f refer to the norms, while R, Y, U and M are drawing symbols. The weld-ability of ribbed steel is described in the section on welding.

Where yield strength is mentioned in this chapter, this can just as well be the 0.2 % stress.

Round steel S235JR (St. 37-2) and S275JR (St. 44-2) have a carbon content of maximum 0.2 % and can be welded without special measures being taken. The steel´s suitability for welding depends on the content of impurities. The carbon content must, therefore, be no greater than 0.22 %.

Type	Designation	Characteristic Yield strength F_{yk} N/mm²	Bending diameter d≤12 mm	d>12 mm	Anchorage factor ξ
	Round steel				
a(R)	S235JR (St. 37-2)	225-235	2 x d	3 x d	None
a(R)	S275JR (St. 44-2)	265	2 x d	3 x d	None
	Ribbed steel				
b(Y)	New tentor, K 550 TS	550	3 x d	6 x d	0.8
b( )	K 550 TS	550	3 x d	6 x d	0.6
	Steel with surface profiling				
f( )	(see product data)	550	3 x d	6 x d	0.4

Table 7.01: Reinforcement types

ϕ mm	6	7	8	10	12	14	16	20	22	24	25	28	30	32	35
R g/m	222	302	395	617	888	1210	1580	2470	2980	3550	3850	4830	5550	6310	7550
Y g/m	228		407	636	915	1240	1630	2540			3970				

Table 7.02: Reinforcement dimensions and weight per metre

Types of reinforcement steel:

Group a: Construction steel in accordance with DS/EN 10025 up and including S235JR, up to and including S275JR.
Group b1: Construction steel in accordance with DS/EN 100025 S355JR (s. 52-3).
Group b3: Hot-rolled ribbed steel and smooth steel with guaranteed upper yield strength in the area up to and including 360 MPa up to and including 600 MPa.
Group f: Steel manufactured from smooth wire with subsequent cold-profiling or ribbing of surface, including stainless steel qualities.

Classification of reinforcement steel

Slack-reinforcement is classified in accordance with the following parameters:

- Upper yield tension or 0.2 %
- Ductility
- Permissible bending diameter
- Production process

Designation of reinforcement steel based on the production process in accordance with DS 13080

a) Production form (rods: reinforcement steel in straight lengths).
b) Standard's number (DS 13080).
c) Nominal diameter.
d) Reinforcement steel for concrete constructions, B, followed by the strength class (B410, B500, B550).
e) Ductility (A = $A_j \geq 3$ % or B = $A_j \geq 8$ %) and anchorage ability (ribbed steel - R, surface profiled steel - P).
f) Production process:
   - hot-rolled, free cooling (+ Q)
   - hot-rolled, rapid cooling (+ AC)
   - cold-rolled or cold-drawn (+ C)
g) Other information:
   - Suitable for point-welding (+ G1)
   - Suitable for back-bending (+ G2)
   - Stainless steel (+ G3)

Example: Rod DS 13080-20-B550BR + AC + G1, which designates reinforcement steel in straight rods in accordance with DS 13080 with a nominal diameter of 20 mm for concrete constructions, with a yield tension, or 0.2 % tension, of 550 N/mm², in Ductile Class B, with a ribbed surface R, and produced by hot-rolling and rapid cooling, and the steel is suitable for point-welding.

Reinforcement steel is delivered with a guaranteed yield tension from the factory, and is subject to one of Danish Standard's approved control systems. Control testing on site is, therefore, not normally required. Certificates or the sub-supplier's attestation is normally sufficient, but a visual control of the markings on the reinforcement steel must be made on site.

All manufacturers and bending plant approved for production, straighten of reinforcement steel from coils, point-welding, high strength welding and reinforcement mesh welding is listed at a register, which might be ordered from the Danish Council of Standardization or other accredited validation organizations

7.3 Practical reinforcement rules

7.3.1 The placing of reinforcement

The reinforcement bars must be placed with such a mutual distance that a good casting and an effective compression (vibration) can take place.

It is important that the reinforcement is placed correctly, in such a way that the designed cover-layer is achieved. Similarly, the construction must not be executed with a greater cover-layer than specified, as this decrease the load bearing capacity of the structure.

Figure 7.01 defines the placing of slack-reinforcement in accordance with the Concrete Norm, DS 411. For the rules for bound and pre-stressed reinforcement, see DS 411.

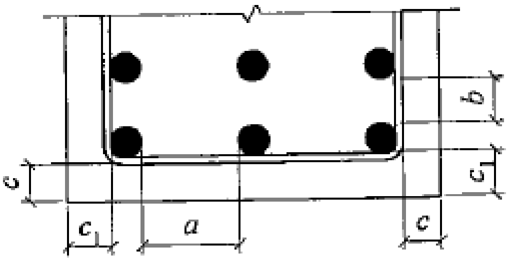


Figure 7.01: The placing of reinforcement

For tightened, normal, and relaxed control (c_1 and c are increased with 5 mm in relaxed control), the following are valid:

$$a \geqq \begin{cases} 2\ \phi \\ d_g + 10\ \text{mm} \end{cases}$$ *Formula 7.01*

$$b \geqq \begin{cases} \phi \\ d_g \end{cases}$$ *Formula 7.02*

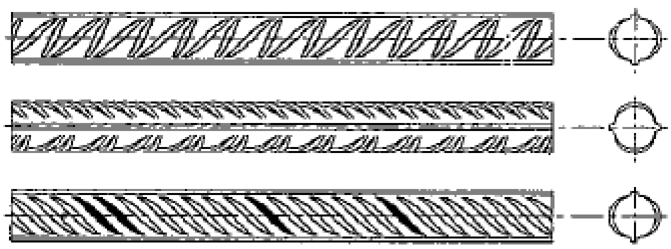
c see Table 7.03

c_1 1.5 φ *Formula 7.03*

- where φ is the reinforcement rod's diameter and d_g is the aggregate's nominal, maximal stone size (d_{max}).

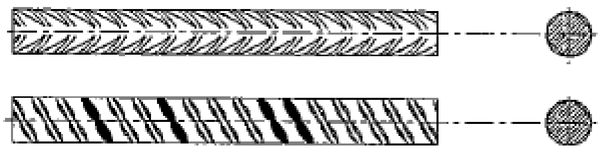
Smaller distances than the aforementioned can be accepted on limited lengths, e.g., in areas with overlapping of rebar occur – if the cover layer is ensured.

Ribbed steel K 550 TS is profiled with slanted ribs: the one side is profiled with 2 thick ribs, 6 ordinary ribs, 1 thick rib, 5 ordinary ribs and 1 thick rib. 1 ordinary rib before the 2 thickened (neighboring) ribs is marked with a nipple. The other side is profiled with slanting ribs, every other rib slants a bit more.

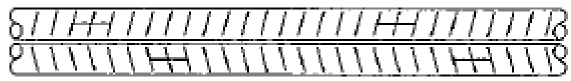


Ribbed steel with comb-like profiling K 550 TS is profiled on the one side with sloped "comb ribs" as: 1 thickened rib, 2 normal ribs connected with a short axial rib, 1 thickened rib, 2 normal ribs and 2 thickened ribs.

Ribbed steel with comb-like profiling K 500 TS is profiled as:
1 thickened rib, 2 normal ribs, 1 thickened rib, 3 normal ribs and 2 thickened ribs.



KS 550 S:
Production mark: over and underside: 13 free spaced ribs between double-H (longitudinally going fins), which is separated by a 1-rib space.



New Tentor/K 550 TS:
Production mark: over and underside: 13 free spaced ribs between 2 double-H (longitudinally going fins) that are separated by a 1-rib space.

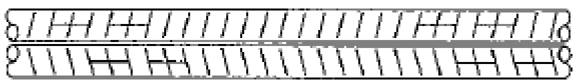


Figure 7.02: Examples of marking of reinforcement steel

Environmental class	Cover layer	Tolerance addendum	Practical cover layer
Extra aggressive	40 mm	5 mm	45 mm
Aggressive	30 mm	5 mm	35 mm
Moderate	20 mm	5 mm	25 mm
Passive	10 mm	5 mm	15 mm

Table 7.03: Cover layer for slack-reinforcement

When casting directly in soil, the prescribed cover layer should be increased by at least 50 mm and, furthermore, the soil should be covered with, e.g., plastic foil or fiber-textile. This extra cover layer can be substituted with a 50 mm layer of concrete blinding, which must have time to cure (solidify) before the reinforcement is laid. In practice, the concrete blinding layer is often thicker than the prescribed as blinding is usually used to even-out the bottom of the foundation trench. Excavators do not remove soil with millimeters' accuracy.

Control of the cover layer's thickness can be implemented after concreting by using a "cover-meter". The principle behind a cover-meter is: reinforcement bars of steel in concrete will change their magnetic field around an electro magnet – the cover meter –, which is moved over the concrete surface. The alterations are dependent on the amount of steel in the concrete and the distance to the steel reinforcement.

7.3.2 Overlapping steels' back-bending

Regarding back-bending, the reinforcement must be approved for this purpose by the manufacturer marking it with G2. The G2-mark means that the reinforcement steel can be back-bent with the bending diameters prescribed by the manufacturer. Table 7.04 shows the rules for back-bending of round steel reinforcement.

Today, much back-bending of reinforcement is done on site where the demands are not met. Only the use of round steel reinforcement for starter-bars to be back-bent is, therefore, recommended.

When reinforcement bars are bent, the temperature must be above 0° C. If the temperature is not above 0° C, the appropriateness of the bending must be documented.

When *hot-bending* is implemented, the rebar is heated up to between 800° C and 1000° C, in which case the steel will be able to attain an arbitrary bending diameter.

	Cold back-bending	Hot back-bending	Original bending diameter	Bending-diameter for back-bending
Round steel d≤12 mm	+	+	2 x d	6 x d
Round steel d>12 mm	+		3 x d	9 x d

Table 7.04: Back bending of round steel reinforcement

The majority of reinforcement types that are produced today are the so-called AC-steels, which is steel that has attained its strength by undergoing water cooling. This steel type cannot, therefore, be hot-bent/hot back-bent. If the steel has to be hot-bent, the execution of this must happen with due consideration to the steel's documented characteristics (contact the manufacturer). Hot-bending cannot, therefore, be uncritically recommended.

7.3.3 Grip and anchorage

Reinforcement must be anchored within the concrete. The stronger the steel, the greater the grip-length, while conversely a stronger concrete binds better to the reinforcement and, therefore, reduces the size of the grip-length.

When reinforcement bars cannot be delivered with sufficiently long lengths, they have to be overlapped so that the one reinforcement bar is fully anchored before the other one ceases in length. The size of the overlap is called the grip-length and is normally equal to the anchorage length.

Regarding the placing of overlaps, the following rules apply: that in slabs maximum half of the rods can be overlapped within the same overlapping length, and for beams the rule is one third – unless the reinforcement's calculatory strength is decreased with 20 %, or the overlap-length is increased with 50 %. The increased grip-length is, however, not required for welded nets of ribbed steel in single-spanned slabs, and the rule does not apply to stirrups.

Reinforcement type	Strength f_{yk} MPa	Concrete strength f_{ck} N/mm²				
		12	16	20	25	≥30
Smooth reinforcement Anchorage factor <0.6 Φ ≤ 10 mm without hook	200 235 275 355	50 51 60 77	50 50 51 66	50 50 50 61	50 50 50 53	50 50 50 50
Smooth reinforcement Anchorage factor <0.6 Φ > 10 mm without hook	200 235 275 355	35 38 45 58	35 35 38 49	35 35 35 46	35 35 35 40	35 35 35 35
Ribbed steel Anchorage factor 0.9	410 500 550	37 45 50	32 39 42	33 36 39	33 33 34	33 33 33
Ribbed steel Anchorage factor 0.8	410 500 550	42 51 56	38 43 48	38 40 44	38 38 39	38 38 38

The table states the condition between the tension-anchorage length and the reinforcement diameter, — .

For reinforcement exerted to pressure, the minimal anchorage length $l = 30\ \varphi$.

Table 7.05: Grip and anchorage lengths.

7.3.4 Prefabricated mesh

Welded reinforcement mesh is advantageously used where cross-reinforcement is necessary in slabs, floors and elements – especially for simple constructions. Instead of binding the rebar on site, the prefabricated mesh arrives as a finished product, which is pre-welded at the intersections of the rebar.

- There are several advantages of using prefabricated reinforcement mesh in comparison to reinforcement rods, which are bound immediately before concreting.
- Time is saved on site. When using loose reinforcement that needs to be bound together into a mesh, there is a tendency to use large dimensions to save binding. Conversely, the overlap lengths tend to be longer. When using welded mesh, the motive to save bindings are gone, therefore, smaller rod dimensions are chosen and thus also smaller overlap lengths.
- The reinforcement is precisely placed and the desired distance between the individual rods maintained.
- The risk of mistakes with reinforcement is reduced.

Standard mesh is produced in lengths and widths of 5000 X 2350 mm, and with other data as given in Table 7.06. The mesh numbers designate rod dimensions and mesh dimensions, e.g., no.6015 is a mesh with 6.0 mm rods and 150mm mesh. Apart from standard mesh, mesh can be ordered with fixed measurements and bent ready for use in the formwork. The bending of mesh can be executed in lengths of up to 6000 mm; Figure 7.03 gives some examples of possibilities.

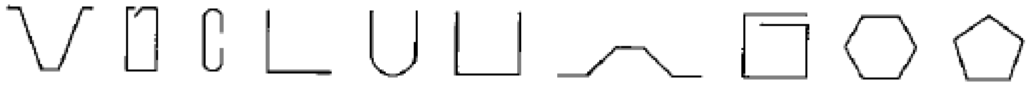


Figure 7.03: Bending mesh into shape

Reinforcement mesh can also be overlapped as shown in Figure 7.04. The free-part of one mesh is decided by the grip-length and distance between the rods.

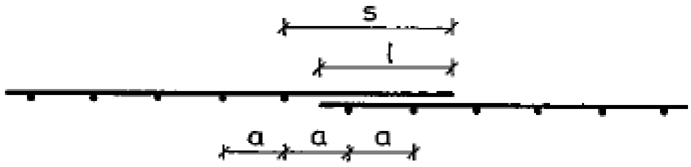


Figure 7.04: Grip in welded reinforcement mesh

Mesh no.	Distance lengthwise rod and crossing rod mm	Rod diameter in mm	Reinforcement area Mm²/m	Weight Approx. kg/m²	Weight Approx. kg/net
5010	100	5	196	3.08	36.6
5015	150	5	131	2.06	24.6
5020	200	5	98	1.54	18.3
6010	100	6	282	4.44	52.7
6015	150	6	188	2.96	35.5
6020	200	6	141	2.22	26.4
7015	150	7	257	4.02	48.3
7020	200	7	192	3.02	35.9
8010	100	8	503	7.90	93.8
8015	150	8	335	5.38	63.2
8020	200	8	251	3.99	46.9
10010	100	10	785	12.34	146.5
10015	150	10	524	8.10	98.7
10020	200	10	392	6.24	73.3
12015	150	12	754	12.08	141.9
12020	200	12	566	8.98	105.5

Table 7.06: Standard mesh

Diameter Φ mm	Concrete strength f_{ck} N/mm²					
	15	20	15	20	25	≥ 30
5	220	210	440	380	330	320
6	240	230	450	390	350	350
7	280	260	530	470	410	390
8	310	300	600	530	470	450
10	390	380	770	660	590	570
12	480	410	830	700	680	680
	Single spanning		Double spanning			

Table 7.07: Overlap and anchorage lengths for welded mesh, f_{yk} minimum 550 N/m².

If the slab is double spanning, this gives more overlapping, which becomes 50 % longer as the rods are overlapped in the same cross-section. The reinforcement consumption is, therefore, increased substantially.

Rod Dia. mm	One rod mm Kg/m	Cross-section/Weight A_s mm²/m for rod distance – kg/m² for rod distance									Rods in 1st space weldable with:
		50	75	100	125	150	175	200	250	300	
4.0	12.6 0.099	252 1.97	168 1.32	126 0.99	100 0.79	84 0.66	72 0.57	63 0.49	50 0.39	42 0.33	4.0 – 7.0
4.5	15.9 0.125	318 2.50	211 1.66	159 1.25	127 1.00	106 0.83	91 0.71	80 0.63	64 0.50	53 0.42	4.0 – 7.5
5.0	19.6 0.154	393 3.08	262 2.06	195 1.54	157 1.23	131 1.03	112 0.88	98 0.77	78 0.63	65 1.51	4.0 – 8.5
6.0	28.3 0.222	565 4.44	377 2.96	282 2.22	226 1.78	188 1.48	162 1.27	141 1.11	113 0.89	94 0.74	4.0 – 8.5
7.0	38.5 0.302	770 6.04	513 4.03	385 3.02	308 2.42	257 2.01	220 1.73	192 1.51	154 1.21	128 1.01	4.0 – 10.0
8.0	50.3 0.395	1005 7.89	670 5.26	503 3.95	402 3.16	335 2.63	287 2.26	251 1.98	201 1.58	167 1.32	5.0 – 10.0
8.5	56.7 0.445	1135 8.91	757 5.94	567 4.45	454 3.56	378 2.97	324 2.54	284 2.23	227 1.78	189 1.48	5.0 – 10.0
9.0	63.6 0.499	1272 9.99	848 6.66	636 4.99	509 3.95	424 3.33	363 2.83	318 2.50	254 2.00	212 1.66	6.5 – 10.0
10.0	78.5 0.617	1571 12.33	1047 8.22	785 6.17	628 4.94	524 4.11	449 3.53	392 3.08	314 2.47	261 2.06	7.0 – 10.0
12.0	113.1 0.888	2262 17.76	1507 11.84	1131 8.88	905 7.10	754 5.92	646 5.07	566 4.44	452 3.55	377 2.96	7.0 – 12.0
14.0	153.8 1.210	3076 24.20	2050 16.13	1538 12.10	1232 9.66	1025 8.07	880 6.90	769 6.05	615 4.84	512 4.03	
16.0	201.1 1.580	4022 31.60	2681 21.06	2011 15.80	1608 12.62	1341 10.54	1149 9.02	1006 7.90	804 6.32	670 5.26	

Table 7.08: Conversion table from one diameter to another

The table above makes it possible to convert one reinforcement member with one rod diameter to another rod diameter by altering the rod in the mesh in question. The two meshes must have the same reinforcement area per m² mesh. The table is read in the following way: The top line in line with the desired rod diameter is chosen first. The next line in the table states the weight in the one direction. Where one desires one rod dimension used in the length-direction and another used in the other direction, the first and last columns are used.

7.3.5 Roll-out mesh

Roll-out mesh is a rational alternative to traditional mesh when reinforcing large slab surfaces, and it is rolled-out like a carpet, which makes it both faster and simpler than a traditional reinforcement mesh.

Roll-out mesh is produced in weld able ribbed steel (Y), in the New Tentor/K 550TS quality, which has steel strips welded-on at 1.8 metre distances and is DS 13080-2 approved. Roll-out mesh is available in the diameters of 10, 12, 14, 16 and 20 mm, and mesh dimensions are optional in whole intervals of 5 mm from 50 mm to 200 mm. The mesh sizes are: width 3-12 metres, optional in whole 10 mm intervals, length 10-30 metres, but maximal 1500 kg per roll. When ordering, the following information must be given: Ribbed dimension D, rolled-out length L, width B, minimum grip zone **a** and mesh **m**.

Note the steel strips are not subject to calculations in the primary construction.

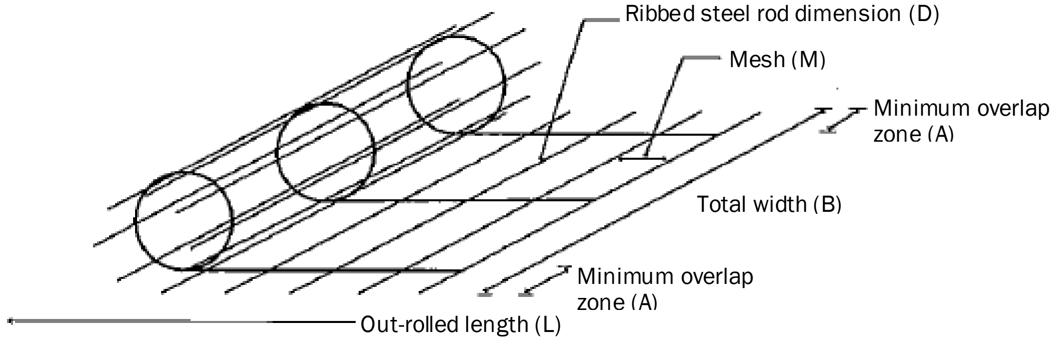


Figure 7.05: Roll-out mesh

7.4 Shaping the reinforcement

7.4.1 Cutting

Several different types of tools can be used for shortening/cutting rebar. Slender rebar up to ø 16 mm can be cut with a bolt cutter; the largest types of handheld el-hydraulic concrete rebar cutters can handle sizes up to ø 20 mm. Handheld concrete rebar cutters can cut bars up to ø 22 mm round steel and ø 18 mm tentor-steel. Most building sites today have stationary el-hydraulic cutting machines. Table 7.09 shows these machines' capabilities. Several bars can be cut simultaneously in situations where smaller dimensions are cut.

Type		S28	S32	S40	S55
Number of rods		1	1	1	1
Round steel	mm	28	32	40	55
Tentor-steel	mm	26	28	32	40
Ribbed steel	mm	20	22	28	34
Cut/minute		40	40	30	15-20
Motor kW		1.5	2	2.5	3
Weight kg		250	400	835	850

Table 7.09: Rebar cutting machines

7.4.2 Bending

Handheld tools or electrically driven tools are used for bending rebar. "The curling iron" is a bending-tool furnished with a long leverage arm, which is used to bend starter-bars and to put the finishing touches on rebar after placing them in the formwork.

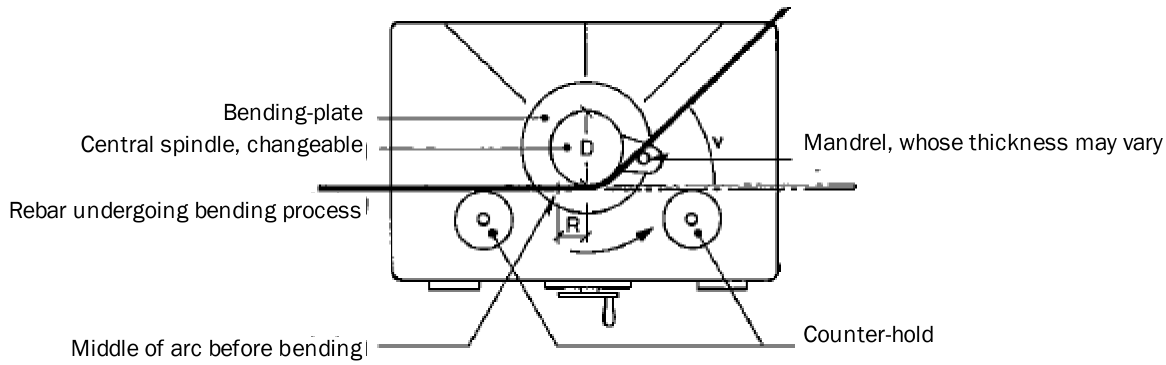


Figure 7.06: Electrical rebar bending-machine.

Smaller profile-bending tools are available for slender bars, which can be used for bending reinforcement for slabs.

Bracket/stirrup-benders, which can be mounted on bending-tables, are available in different types of which the simplest consists of a bottom plate with a mandrel and a profile-steel arm that can be turned. Round steel rods with a diameter up to 12 mm can be manually bent on this machine. The principle for a bending machine is shown in Figure 7.06, where the bending-plate is furnished with a mandrel that turns in a clockwise direction and bends the rod to the desired bending-angle. The machine is also furnished with a counter-hold, and the central spindle can be interchanged dependent on the bending-angle, D, that needs to be achieved. Table 7.10 shows an example of three different sizes of bending machines.

Normally, the bending-plate turns with the rod during the bending turn. The middle of the finished arc (piece R) is, therefore, placed in front of the place where the mandrel grabs the rod at the beginning of the turn. For R, the following is valid:

$$R = \frac{\quad}{\quad} \cdot D \qquad \text{Formula 7.04}$$

where V is the bending-angle.

Type		B 32 Standard	B 40 Standard	B55 Extended
Number of rods		1	1	1
Round steel	mm	32	40	55
Tentor-steel	mm	26	32	45
Ribbed steel 550	mm	22	26	40
Bending-plate	turns/min.	10	10	5-16
Motor	kW	2	2.5	5.5
Weight	kg	410	460	1245

Table 7.10: Bending machines

7.4.3 Processing rebar on fully automated machines

Fully automated machines are used at rebar stations, but they usually only process rebar dimensions from 5 to 16 mm and they use reinforcement bars from “coils” (a coil is a reinforcement bar that, after production by hot-rolling or cold-deformation, is wound-up into rolls to be straightened-out before use).

Coils are delivered from the steel supplier in the rolled-up state in units of 1.5 to 2.5 tons. The rolled up coils are straightened and bent on fully automated bending/straightening machines, which results in precise products and good work-environmental conditions. These machines are, however, because of price, size and the extent of control provisions, reserved for rebar stations. All reinforcement delivered from such machines observes the demands and requirements of Danish approved reinforcement steel.

7.4.4 Binding reinforcement

Tie-wire and tongs, or spiraling tie-tongs that grab two “eyes” or “loops” on prefabricated tie-wire and twist the two wire ends into a knot when pulled by the tong, are used to bind the rebar at intersections.

The rebar is, as a rule, tied at every other intersection - dependent on how dense the rebar is, as the purpose of binding is to hold the rebar in place during the pouring and curing of the concrete.

Annealed steel wire with a dimension of 1.5 mm is usually used for binding rebar. The consumption of tie-wire is about 5 kg per ton rebar.

When binding rebar with tools like the ordinary binding-tong or spiraling tie-tong, the process of binding requires being close to the place of binding, which results in a bad working-posture and, in cases of binding reinforcement in slabs, can result in back-damage. A binding-apparatus has been developed which makes it possible to bind rebar and place spacers from a standing posture. This apparatus is, however, not widespread in the industry yet.

7.4.5 Spacers

Spacers are placed under reinforcement to ensure the required concrete cover layer. These can be made of plastic members that are wedged around or fixed to reinforcement steel rods, or they can be made of concrete briquettes with associated tie-wire.

Spacers must be sufficiently stiff to resist the crushing weight of being trod on, and they must be fixed so that they do not capsize and buckle. The consumption of spacers varies with the dimension of the rebar (dependent on how self-supporting the rebar is), but on average, the consumption is 200 units of spacers per ton reinforcement.

Figure 7.07: A selection of rebar spacers

A commonly used plastic spacer briquette is “Kejserkronen” (“the Emperors’ Crown”), which, unfortunately, has the drawback that concrete has difficulty filling it. Consequently, the rebar does not get a sufficient cover layer of concrete from this spacer and corrosion damage can easily occur and develop if moisture seeps into the hollows of the spacer.

Spacers called “chairs” are often used to keep the distance between top-side mesh and bottom-side mesh in concrete decking and slabs. If these are produced on site, they are often made of T/K 16-25 mm for very large spaces, but only R 16 mm or T 12 mm is used for normal slab thicknesses. An example of a “chair” is shown in Figure 7.09, and 1 chair per m² slab is normally used. Prefabricated spacers are also available for separating mesh in slabs. The one shown in Figure 7.08 is a so-called “mouse ladder” and is available in heights ranging from 30 to 300 mm in intervals of 10 mm.

When rebar rests on spacers or “chairs”, it is important that the bending of rebar that occurs observes the tolerances for the placing of the rebar.

R10 mm U-brackets per m² wall are used to keep the distance between mesh in a walls. There are several prefabricated spacers available on the market today. They are made of one piece of steel furnished with a plastic peg at the end to which the rebar can be fixed. They function as mesh spacers and ensure the correct slab thickness.

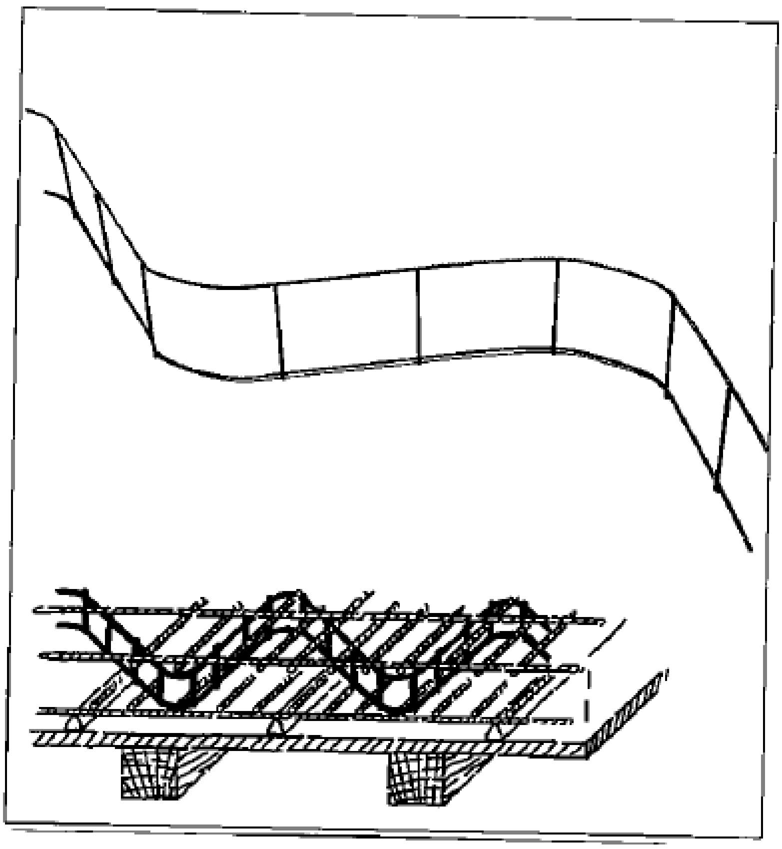


Figure 7.08: Spacers (mouse ladder) for slab reinforcement

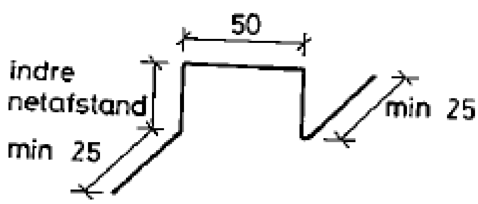


Figure 7.09: Spacer (“chair”) for slab reinforcement

Figure 7.10: The laying down and binding of slab reinforcement

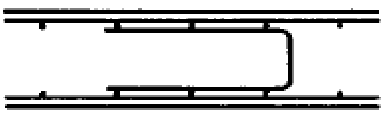


Figure 7.11: Spacers for wall reinforcement mesh

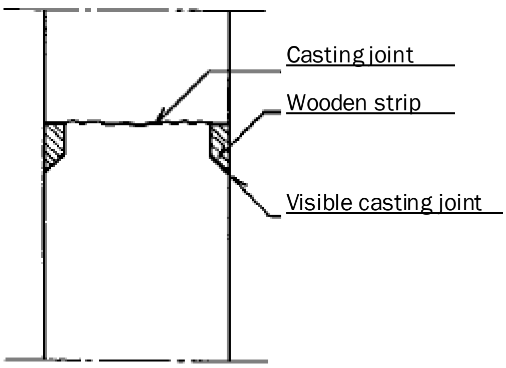


Figure 7.12: Horizontal casting joint in wall

7.4.6 Casting joints and starter-bars

When a concrete pour is expected to be interrupted for more than 1-2 hours, dependent on the temperature, cement type and possible retardant additives in the concrete, a casting joint must be established. The extent of the concrete pour and the provisions against the formation of cracks due to shrinkage are also a factor when choosing the positioning of the casting joint.
In some projects, the positioning of casting joints are stipulated in the tender documents, but otherwise, the contractor is able to decide the positioning of the casting joints himself if the client's site inspection does not have special requirements for their positioning. The casting joint should be placed at places where tensions are minimal and as far as possible perpendicular to the direction of pressure.

Casting joints without formwork are used where the surface is horizontal as, e.g., at the top of walls or columns. In these cases, the pour is interrupted in the planned height, normally 10-20 mm up into the planned slab construction. It is occasionally seen that casting joints are pressure-cleaned, or a 10 mm cement mortar layer is laid down in the same mortar as used in the pouring concrete before the pour is resumed. Similarly, there are examples of the cured concrete being moistened repeatedly the last day before pouring so that it does not absorb water from the poured concrete. The concrete surface must, however, have a dry surface so that it does not give-off water to the new poured concrete.

It may be necessary to install heat cables in winter in the poured concrete near the casting joint in order not to get too great a temperature difference in the newly poured concrete.

A regular horizontal and/or vertical casting joint can be created by the contractor by inlaying trapezoid wooden strips. The use of wooden strips sometimes counter acts the tendency for a wall to get thicker and thicker for each casting joint.

Casting joints with formwork is used when the former is vertical, as with slabs and concrete beam constructions and at the end of a wall. See Figure 7.13.

The delimitation of the casting can be established by using timber, as shown in Figure 7.13, where starter bars penetrate through drilled or cut-out holes in the formwork. In order to ensure the transference of shear forces, the casting joint can be formed as an interlocking groove structure by insertion of wooden profile-strips forming the groove in the delimitation formwork.

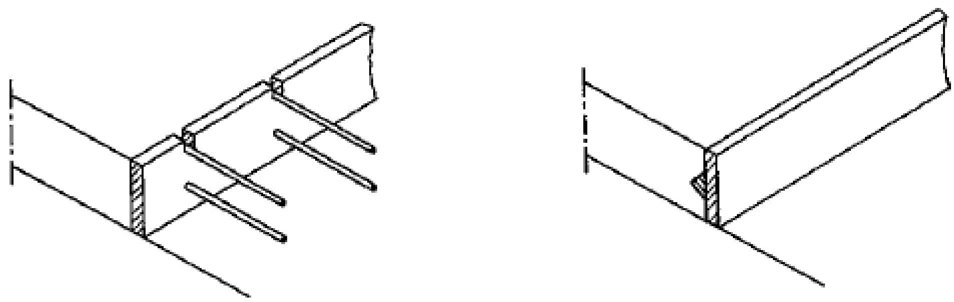


Figure 7.13: Vertical casting joint in slab with wooden formwork, starter-bars and interlocking groove solution.

Timber as delimiting formwork is difficult to deal with when the formwork has to be struck because of the many starter bars protruding out of the structure. When the formwork is struck, it may be difficult to get all the timber out. However, instead of timber expanded metal, which is basically a steel plate which is punched out with slits and then drawn to form grill mesh, can be used. This has the advantage that the starter bars can be pushed through the apertures in the expanded metal mesh and the mesh only needs to be removed in aggressive or extra aggressive environments.

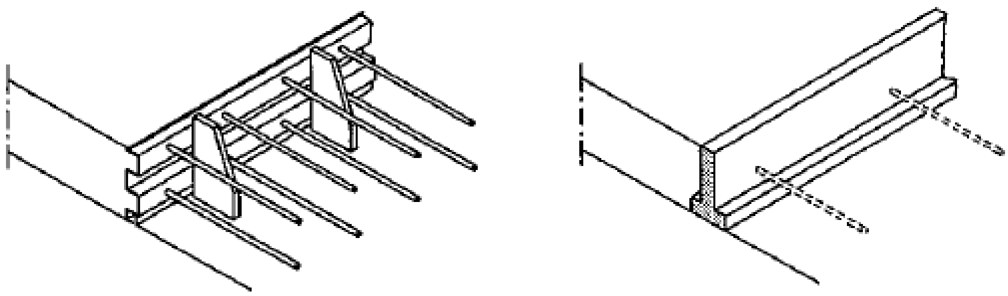


Figure 7.14: Vertical casting joint in slab with, respectively, Comax-profile and Kota-profile

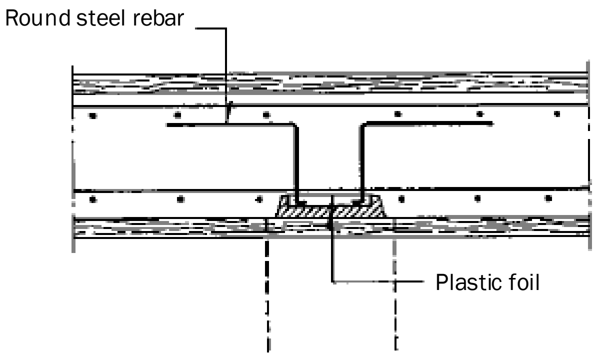


Figure 7.15: Horizontal section in wall with starter-bar box.

Furthermore, an even casting joint with regard to evening out the shear forces is achieved as concrete seeps through the mesh-holes of the expanded metal. Nowadays plastic mesh with the same appearance often replaces expanded metal. The plastic mesh must, however, be removed before continuing the pour. A fourth solution is the use of prefabricated Comax steel profiles. This product can be used only once; see Figure 7.14. A fifth solution is the Kota-profile, which is made of concrete and can, therefore, be permanently cast into the construction with an open surface for the transference of shear forces, and with holes in the middle of the profile height for the insertion of starter-bars. This produces two shrinkage cracks at each casting joint.

Where costly formwork is used, e.g., for large element formwork, which preferably should not be perforated and where casting joints must be established for an adjoining wall, starter-bar boxes as shown in Figure 7.15, are used. The box comprises a piece of fashioned timber, which is covered with a plastic foil through which bent starter-bars are inserted. The box can be removed after the formwork is struck and reused again. The bent starter-bars are straightened so that they can be cast into the adjoining wall.

There are many prefabricated starter-bar boxes available on the market, which are able to compete with wooden starter-bar boxes because of the low amount of work necessary to mount them and strike them.

As an alternative, it may be worth examining a solution where it is possible to drill and glue starter-bars after casting and striking the formwork.

7.5 Rebar cutting list

The project drawings form the basis for production. The designer´s drawings comprise first and foremost the construction drawings that are sometimes processed into production drawings. This is the case for reinforcement drawings that form the basis for establishing rebar cutting lists. The cutting lists are done on special forms whose layout can vary form company to company. Figure 7.17 shows an example of this type of form.

When working-up a cutting list, the construction or structure is normally processed from the bottom up so that each member is processed separately. The individual reinforcement members are drawn out of the drawing in question as these are "read" from left to right. The primary reinforcement components are stated before secondary ones.

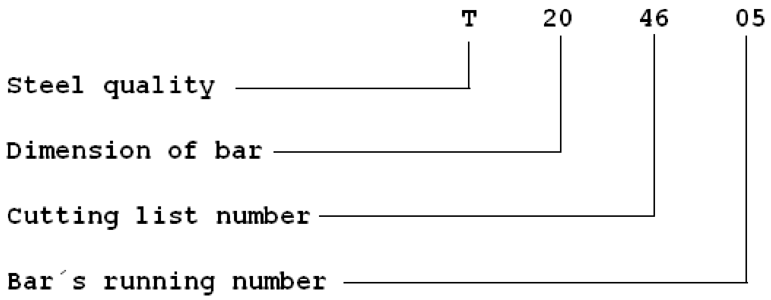


Figure 7.16: Example of reinforcement steel nomenclature

The name of the construction component, e.g., concrete beam in basement, is entered under the heading "Use". It is good practice for each construction component to have its own cutting and bending list.

"Marked" designates the rebar number of the individual rebar rod. This number can be made-up as shown in Figure 7.16. The number is also shown on the production drawing, and the actual cut and bent rebar member is also given a label from production on which the number is stated.

The next column states "Symbol" and "Dimension". Symbol is an abbreviation, e.g., R for round steel bar, which is often used in construction drawings.

The column "Quantity" speaks for itself.

The design of the reinforcement steel member is drawn under the heading "Sketch" with the necessary dimensions for forming it. It is common practice to state the external dimension and state it on the bending and cutting list. It is common, for example, for the measurements of stirrups to be calculated by subtracting the slab layer plus tolerance from the beam's geometric dimensions.

When working-up reinforcement lists, consideration should be taken to the fact that normal bending machinery do not process reinforcement pieces that are less than 8 times the reinforcement diameter.

The bending of rebar happens on bending-plates whose size depends on the quality and dimension of the rebar. It is important that there is coherence between the bending-plate diameters that form the basis for the determination of bending and cutting lists and those that are used for bending the rebar, as the calculated cutting lengths otherwise will not tally. The bending-diameter is only stated if it is greater than the norm's minimum diameter. The bending-diameter is given as an internal measurement.

Bending list no.: Page no.:

Designed by: Date: Corrected by: Date: Case no: Drawing executed by:

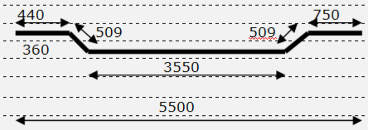
Member no.	Bar mark	Steel Type	Steel Bar dia.	No of bars in member	Cut length mm	Profile height mm	Bending disc diam. mm	Shape (all measures are external dimensions in mm)	Remark
B2, B2A, B2	1+3+5	T	16	3	13400			 13400	
"	2+4	T	16	4	5798	360	96	 440; 509; 509; 750; 360; 3550; 5500	

Figure 7.17: Cutting-/bending list

The cutting-lengths give the reinforcement steel´s length after cutting. The column "@" states the number of reinforcement bars which are cut and there lengths before cutting measured in metres.

When calculating the cutting lengths of reinforcement for bending, the sum of the outer dimensions must be adjusted. This is because the reinforcement does not appear as measured straight lines after bending, but as parts of circle arcs. The deduction can be calculated as follows:

Deduction $= 2 \cdot \left(\frac{D}{2} \cdot f + \phi\right) \cdot \left(\tan \frac{V}{2}\right) - \pi \cdot \frac{V}{360} \cdot (D \cdot f + \phi)$ Formula 7.05

where D is the bending diameter, φ is the reinforcement diameter, and the spring-factor f = 1.10 for φ ≤ 12 mm and 1.12 for φ > 12 mm. V is the bending angle.

The stirrups for a beam will have width and height, which correspond to the cross-section of the beam - (cover layer + tolerance). The stirrups' cutting length will be 2 stirrup heights + 2 stirrup widths - 4 · "corner deductions" + 2 · hook lengths (10 x φ).

The remainder (remainder should really be called usable remainder) must, therefore, be minimum 2 times the anchorage length, corresponding to approximately 1 m. It must also be stated for which reinforcement number this remaining piece should be used.

When the cutting length is determined, a position can be taken as to which reinforcement steel it should be cut from. These can be directly purchased in trading lengths of, e.g., 10, 12, or 14 metres, or they can be leftovers from other rebar that has been cut. By combining trading lengths with the desired cutting lengths in a reasonable way, the cutting waste can be minimized to approximately 8 % of the purchased amount. It is not, however, reasonable to order different lengths of the same reinforcement steel diameter.

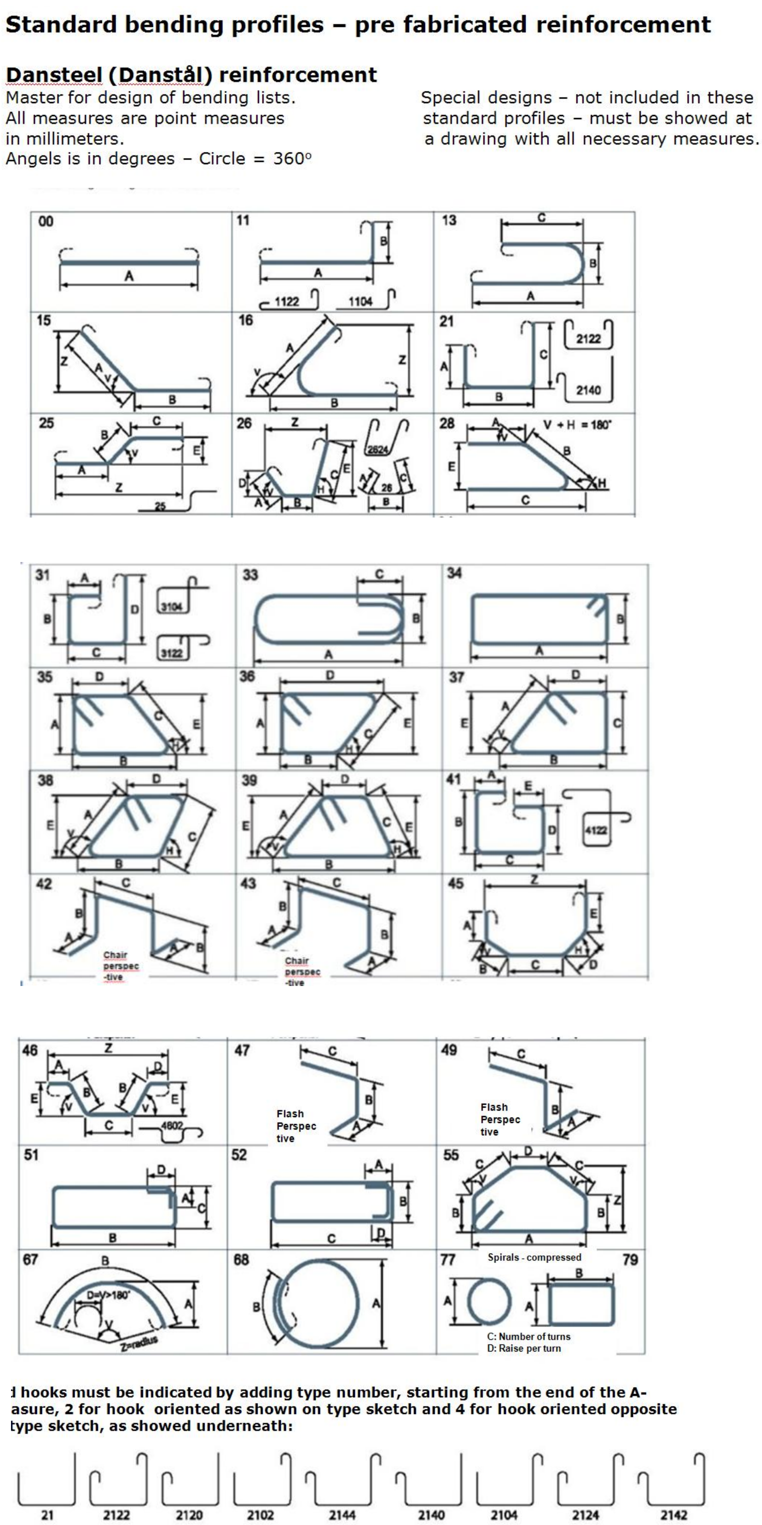


Figure 7.18: Type information

Cutting waste from small dimensions can, furthermore, be used as spacing steel for wall reinforcement in double-reinforced walls, for "chairs" for uppers slab reinforcement, for coupling-rods, or for starter bars. Non-usable cutting waste is sold as scrap metal.

Figure 7.18 shows a type list for designing of cutting- and bending lists. This kind of a type list is especially suitable for EDB-based designing of bending lists – often used at reinforcement stations.

7.6 Check list for reinforcement control

- Are the number, type and diameter of reinforcement correct?
- Are the spacer bricks large enough? Are they placed close enough?
- Are the bending radiuses suitable for reinforcement type and diameter, and for the compression strength of the concrete?
- Are the reinforcement bars placed according to the Euro Code? Is the distance between ties correct?
- Is there enough space for casting and vibrating – even at the reinforcement grips?
- Are the grip length´s sufficient? Do you have grips for too many rods within a normal anchorage length?
- Are the reinforcement properly placed over the bearings. Is the anchorage OK?
- Are the grip reinforcement properly placed in the previous casted concrete?
- Are the top reinforcement placed high enough in a slab? Are the top reinforcement placed too high? Will it stay in the right position during casting?
- Are the recesses placed at the right position? Will they stay in the right position during casting?
- Is there compensated for the changes in the subscribed reinforcement at the recesses?
- Are there enough bindings?
- Have you implanted reinforcement described in the general description, but not shown at the reinforcement drawing?
- Carry out extra control in places, where the reinforcement arrangement deviates from “normal standard”.
- Is there any deformation at the reinforcement arrangement?
- Are the entire bend up´s placed in the correct position?
- Are there pollution from soil, loose rust, oil spill, ice or similar placed on the rods?
- Is cut off from tie wire removed from the bottom of the formwork? Critical when you are casting a slab.

7.7 Welding

Welding of reinforcement steel should be done at a factory or a reinforcement work shop. Welding on site should be avoided and if it must be done, the welder has to be certified to weld reinforcement steel and one must fulfill the demands in the Euro Code.
Normally this will only be possible at very big sites, like a Great Belt Bridge or similar. One must distinguish between strength welding of force absorbing reinforcement rods and manual point welding just to tie the rods, like bindings, keep it in position during transportation, mounting and casting.
By welding of reinforcement steel you must assure that the rods are marked G1, and that all welding fulfill the descriptions of the steel manufacturer.
If welding is necessary, an accredited validation organization (certification of welding) and the consulting engineer must be contacted.