REINFORCING TECHNIQUE WITH BSt 500
The networking of all parties to reduce costs and improve quality

Prof. Dr. Ing. D. Jungwirth

China, May 2003

Summary

Reinforcement is the soul of reinforced concrete construction and holds together the concrete. It is embedded in concrete, invisible and usually badly paid. This paper will focus on the necessity of forming a network of all parties involved. It will point out various possibilities of improving quality and of minimizing costs as well as ways of further developing the reinforcing technique. This paper will mainly consider high-strength steel BSt 500 (yield strength 500 MPa) as used in bars, rings or welded fabrics.

1 Introduction

Today’s state of the art is based on German/European experiences that are also applicable to China. In Germany, 4 million tons of reinforcing steel are installed per year, which amounts to 50 kg per citizen and year.

Fig. 1 illustrates the annual consumption over the past years. Steel grade BSt 420 was still predominantly used in Germany 20 years ago. Today this grade has been almost exclusively replaced by the steel grade BSt 500. The price / performance ratio improves with increasing steel strength (price per 1 Mp and per m).

Reinforcing steel BSt 420

\[
\text{price per ton of steel} \times 0.0785 = 27500 \times 0.0785 = \frac{27500 \times 0.0785}{420} = 5.1 \text{ Cent/Mp·m}
\]

Reinforcing steel BSt 500

\[
\frac{28500}{500} \times 0.0785 = 4.4 \text{ Cent/Mp·m}
\]

Prestressing wire strand 1860/1600

\[
\frac{65000}{1600} \times 0.0785 = 3.2 \text{ Cent/Mp·m}
\]
The anchoring behaviour of reinforcing steel is optimal. The crack and deformation behaviour is not affected adversely by the high strength. The costs for the reinforcement in reinforced concrete construction amount to approx. 10 to 15% of the overall shell construction costs (in bridge construction with prestressed reinforcement the costs amount to approx. 20 - 30%).

The average price for one ton of reinforcement is

<table>
<thead>
<tr>
<th>Material</th>
<th>Price (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforcing steel</td>
<td>285,--</td>
</tr>
<tr>
<td>Welded fabric</td>
<td>450,--</td>
</tr>
<tr>
<td>Bending</td>
<td>125,--</td>
</tr>
<tr>
<td>Installation</td>
<td>220,--</td>
</tr>
<tr>
<td></td>
<td>630,--</td>
</tr>
</tbody>
</table>

\[ 630,-- \approx 56.60 \]

Chin. Currency 8,8897 Renminbi = 1 €
0,089 Renminbi = 1 Cent

The reinforcements are installed by specialist companies. Very few construction companies have their own installation crews, making it all the more important to form a network between all parties involved, comprising

- Planning
- Design and construction
- Job preparation including calculation
- Bending and installation companies (specialist companies)
- As well as acceptance

Table 1 illustrates the network, including accompanying works and modules of the reinforcing technique. These sections / modules will subsequently be dealt with and explained in more detail. Table 1 represents so to speak the table of contents of this paper.

NETWORK AND PROCESS ORIENTED PROCEDURE

2 Planning

The planning of a structure may already have an influence on the costs for the reinforcement. Recurring dimensions of the same size would be of advantage,
and could then be reinforced according to the modular design principle. Sufficient time must be allowed for planning.

3 Design

Basis for the dimensioning of sectional forces and design is the Euro code EC2 or prEN 1992-1:2001, which also formed the basis for the new German standard DIN 1045-1:2001. Dr. Litzner will inform you in more detail on that point.

EDP (electronic data processing) is increasingly used in the design of structures, which is positive. On the other hand, however, the innate feeling for structural stability is on the decline among designers. EDP is like a black box: its results are often accepted without questioning. This makes it all the more important to assess in advance the results by use of simple load bearing analogies which in turn helps to improve the design and to check the EDP results. In many cases, simple strut and tie analogies or approximate formulas are sufficient.

It would also be of advantage to use only a steel grade, which is easily obtainable on the market, BSt 500:

Yield strength 500 N/mm²
Weldable
Strong bonding behaviour
High ductility
High fatigue strength

This steel is regulated by the new DIN 488 (partly according to prEN 10080). Dr. Russwurm will inform you in more detail about this reinforcing steel. Provision must be made in the design for adequate minimum reinforcements and system reserves, which may be required for ex. in case of fire. It does no good to determine the reinforcement (mass minimization) which is theoretically required by extensive calculations.
This reinforcement is generally more expensive and deprives the structure of its robustness and system reserves.

4 Construction

EC 2 also provides a good basis in construction. Again Dr. Litzner will inform you in more detail on that point. In addition, there are a great number of other regulations and documents on design and execution, as for example the instruction sheets issued by the DBV (German Association of Concrete and Construction Engineering), excerpts of which are listed in Table 2.

In construction cooperation between all parties involved is of the utmost importance, that is between:

- Structural engineer: design/construction
- Construction company: job preparation etc.
- Specialist company: bending and installation

Primary goals and detail improvements must, however, always be considered. Primary goals are:

- Acceptance of reinforcing elements and welded fabrics
- Continuous EDP from PC to CAD, CAM, CIM, and robotics (Table 3)
- Improvement of framework edges (Fig. 2)

In detail the reinforcing technique may be improved by various methods:

- Use of few different bar diameters, preferably large diameters with surface reinforcement (Fig. 3)
- Few bend formations
- High number of pieces of individual units
- No bending up; straight bars
- Few loops
- No steel bending at column (Kröpfung)
- No fit pieces
- Special welded fabrics for edges (Fig. 4)
- Basic elements with additional reinforcement (Fig. 5)
• Stirrup ladders, stirrup mats (Fig. 6)
• Connecting elements (Fig. 7)
• Connections to formworks (Figs. 8 + 9)
• Anchor devices (Figs. 9 + 2a)
• More prefabrication

All these are illustrated by the examples represented in Figures 2 to 9. More information on jointing techniques (connection and anchor devices) is given in section 13.

5 Job preparation

A functioning network between structural engineers, job preparation, bending and installation companies makes it possible to optimise the total cost, by choosing an appropriate reinforcing method (prefabrication), which is integrated into the overall construction process (logistics). The costs for individual construction works may be higher, but this may help to save money in other parts of the construction. Therefore, one has to consider the overall construction costs, for example:

• Construction cycles may be accelerated by using big, stiff, prefabricated reinforcement cages which are more expensive (for ex. in segmental construction), but construction can proceed independent of time and whether.
• In segmental tunnel construction with restricted space conditions the threaded connections of the more expensive jointing method are the appropriate solution as considered from an overall economic point of view, as well as with regard to quality improvement.
6 Bending and installation companies

The structural engineer requires a simple calculation model by which he can determine the economical layout of reinforcement required in each particular case. In some cases, higher mass which are easy to install may be cheaper than the installation of low mass of reinforcement.

To ensure a continuous EDP the reinforcement drawings with the various bend formations must be passed on from CAD to the bending company's CAM and CIM.

The bending and installation company must have

- trained and qualified personnel
- should be organized in accordance with a quality management system in compliance with DIN ISO 9000
- the intersection to acceptance could then be easily regulated by internal and external supervision.

In Germany a "supervision body of bending and installation companies" is in the process of being formed (example Table 4).

7 Acceptance

For acceptance, the difficulty and importance of a structure must be taken into consideration. 3 classes are proposed, requiring controls of varying extent and performed by different bodies (in Germany there exist as yet no uniform regulations).

A simple structures, such as small apartment houses control by QS-Management of installation company
B standard structures, such as standard bridges, industrial plants external control by construction company
C structures in which safety is an important factor control by official authorities
What has to be checked (see too DIN 1045-3):

- Steel grade
- Mechanical connections
- Welding
- Concrete cover, Supports, Spacer
- Joint lengths
- Anchorage lengths, displacement M/z
- Number of bars and diameters
- Spacing
- Connecting reinforcement
- Space for compacting
- Gangways for casting
- Clean reinforcement.

OVERLAPPING TASKS

8 Quality management (QM)

As has already been mentioned in section 6, all parties involved in construction (sections 2 to 7) should be integrated into a continuous, process-oriented QM-system. A comprehensive subject in itself, a QM-system should include the following main elements:

- Organization structure of the company, responsible persons, procedures, auditing
- Contract control
- Developments, technical processing
- Purchase
- Designation, traceability, deviations
- Quality control
- Documentation
- Qualification of personnel, training
- Manuals, instruction sheets, checklists
9 EDP, CAD, CAM, CIM

As has already been pointed out in section 4, Table 3 and section 6, this should be a continuous process. In this way, dangerous transmission errors (numerical data errors) at the intersections of the individual parties involved may be avoided. This saves time and money.

10 Contracts for all parties involved

The strong parties – which, in most cases, are those who award the contracts - tend to emphasize their own interests in the contracts. However, a contract should be in the interest of all parties involved, if it is to be maintainable over a longer period of time. Otherwise the weak party will be put at a disadvantage and may even go bankrupt. He would have to be replaced by a new member which will cause loss of time and money.

MODULES

11 Reinforcing steel

As has already been pointed out, this subject will be dealt with in more detail by Dr. Russwurm. The discussion will focus primarily on reinforcing steel BSt 500. In a few cases higher grades such as BSt 650 or 700 have been used in Europe. These steels are, however, not readily available on the market. Planning and design have to be modified, if these have previously been based on BSt 500. BSt 650 or 700 go to the limit of usability as regards crack widths and deformation.

In some special cases even high strength steels such as St 1100 are used. These are treated, however, in the same way as BSt 500 in the service state and only used for “exceptional impacts” such as airplane crashes or for special load cases in earthquakes (see paper by Prof. Macchi). The structure must not collapse under these limit states; it can, however, no longer be used.
12 Reinforcement regulations

Dr. Litzner will inform you in more detail on that subject. Here it shall only be pointed out once more that BST 500 has never caused any problems either with regard to the anchorage, or the required compliance with allowable crack widths in the service state (Table 5) nor have its deflection values ever attained inadmissible limit states. Larger diameters are even preferred on account of their robustness and easier casting. The installation of reinforcement at construction joints (for ex. Fig. 9) and the standardization of reinforcement installation by a “handbook of standardization” is also worth mentioning.

13 Jointing methods

These have already been shortly referred to in section 4. Fig. 10 shows that with close joint spacing coupled joints are cheaper than overlapping joints, apart from the fact that this also makes casting easier due to the low concentration of reinforcement. Shattering, as may happen with overlapping compression joints on account of the high pressure at the bar ends, may be ruled out (Fig. 3). Coupled joints are therefore preferably used in Europe and are available on the market in many different types (Table 6). The typical characteristics of the various joint types are summarized in Table 7.

14 Prefabrication

The advantages offered by prefabrication (delivery just on time) have already been pointed out several times. Here are some additional criteria and information on the subject:

- Prefabrication of elements (special welded fabrics, cages, rolls, edge mats, stirrup mats, framework edges, tube reinforcements)
- Standardization of reinforcement installation
• Standardization of construction products (columns, consoles, beams, framework edges, truss joints)
• Problems with regard to the connection of reinforcements
• Tolerances

15 Qualification

As has already been mentioned in section 6 in connection with the bending and installation companies, all parties involved must be qualified and must receive basic and continuous training. Today training is made easy by the use of CDs and the Internet. The introduction of a new professional title of “installation specialist” analogous to that of the already existing title of “concrete specialist” is being considered.

16 Prospects and perspectives

Prestressed reinforcements and alternative materials such as steel fibres, glass fibres, plastic and carbon fibres have not been dealt with in this paper, although there is a market also for these fibres. Improved corrosion protection systems such as galvanizing or epoxy coatings have also not been mentioned. Goals and ideas may be summarized as follows:

• Overall cost consideration
• Prefabrication
• Corrosion protection systems
• Fibres
• More self-compacting concrete
• Reactive powder concrete
• Quality improvement
### Table 1: Reinforcing technique

<table>
<thead>
<tr>
<th>Process oriented procedure</th>
<th>Overlapping tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Surroundings(social, political), introduction</td>
<td></td>
</tr>
<tr>
<td>2. Planning</td>
<td>11. Reinforcing steel state as delivered, diameter, etc.</td>
</tr>
<tr>
<td>3. Design</td>
<td>12. Reinforcement regulations DIN 1045-1, EC2</td>
</tr>
<tr>
<td>6. Bending company, installation company</td>
<td>15. Qualification</td>
</tr>
</tbody>
</table>
| 7. Acceptance             | ..........
| 16. Prospects and perspectives (further developments) |     |

|--------------------------|--------------|---------------|

### Table 2: Excerpts from the DBV instruction sheet collection

1.4 Limitation of crack formation in reinforced concrete and prestressed concrete Construction
1.5 Watertight concrete construction body
1.6 Limitation of thermal cracking in the concrete
2.1 Concrete cover and reinforcement
2.2 Spacer
2.3 Supports
2.4 Re-bending of reinforcing steel and requirements for pocket formers
2.5 Castability of construction elements made of concrete or reinforced concrete
2.6 Casting in the winter

### Table 3: Continuous EDP concept from planning to installation of reinforcements

```
PC  EXPERT SYSTEM
PERSONAL COMPUTER
CAD
COMPUTER AIDED DESIGN
CAM
COMPUTER AIDED MANUFACTURING
CIM
COMPUTER INTEGRATED MANUFACTURING

ROBOTICS
```
Table 4: Organization structure of supervision body

- Bending / installation company
  - Quality control / supervision body
- Construction site A / construction site B / construction site C
  - Reinforcement specialist
- Responsible construction company

Table 5: Maximum bar diameters $\varnothing_s$ for high bond bars, according to Table 7.3 of prEN 1992-1

<table>
<thead>
<tr>
<th>Steel stress $[\text{N/mm}^2]$, SIS</th>
<th>Maximum bar size $[\text{mm}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$W_{Kx} = 0.4\text{mm}$</td>
</tr>
<tr>
<td>160</td>
<td>40</td>
</tr>
<tr>
<td>200</td>
<td>32</td>
</tr>
<tr>
<td>240</td>
<td>20</td>
</tr>
<tr>
<td>280</td>
<td>16</td>
</tr>
<tr>
<td>320</td>
<td>12</td>
</tr>
<tr>
<td>360</td>
<td>10</td>
</tr>
<tr>
<td>400</td>
<td>8</td>
</tr>
<tr>
<td>450</td>
<td>6</td>
</tr>
</tbody>
</table>

\[
W_K = S_{\text{max}} \cdot (\varepsilon_{Sm} - \varepsilon_{Cm})
\]

\[
\varnothing_s = \frac{\sigma_s - \alpha_s\frac{f_{\text{ct,eff}}}{f_{\text{p,eff}}} \cdot (1 + \alpha_e \cdot \varnothing_{p,\text{eff}})}{3.6 \cdot \varnothing_{p,\text{eff}}} \cdot \frac{\varepsilon_{s}}{E_s}
\]

\[
S_{\text{max}} \leq \frac{\sigma_s \cdot \varnothing_s}{3.6 \cdot f_{\text{c,eff}}}
\]

\[
\varepsilon_{Sm} - \varepsilon_{Cm} \geq 0.6 \cdot \frac{\sigma_s}{E_s}
\]

\[
\alpha_e = \frac{\varepsilon_s}{\varepsilon_{Cm}}
\]
Table 6: Standard joint connections

- GEWI methods
- Lenton joint
- WD couplers
- Extruded coupler joint
- Compression joint
- HBS joint
- CADWELD casting joint
- Welded joint

Table 7: Characteristics of joint connections

<table>
<thead>
<tr>
<th>Formwork connection difficult</th>
<th>Saw cutting required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatigue strength</td>
<td>Longitudinally displaceability required</td>
</tr>
<tr>
<td>Slip under load</td>
<td>Bended bars prevents twisting of bars</td>
</tr>
<tr>
<td>Tumbuckling possible</td>
<td>Sensibility during assembly</td>
</tr>
<tr>
<td>Transition couplers from $\varnothing_1$ to $\varnothing_2$</td>
<td>Equipment requirements</td>
</tr>
<tr>
<td>Compensation couplers</td>
<td>Space requirements</td>
</tr>
<tr>
<td>Site controls expensive</td>
<td></td>
</tr>
<tr>
<td>Costs: materials and salaries</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 1: Consumption of various types of reinforced concrete in Germany

Crack angular to the steel: additional reinforcement

Fig. 2: Edge joint formations

a) simple reinforcement, more mass
b) minimum reinforcement, special parts

Fig. 3: Large diameters of reinforced concrete with crack distributing surface reinforcement
Fig. 4: Edge formation by loop-body consisting of welded fabrics

Fig. 5: Penetration of column-reinforcement and beam elements

Stirrup mat

Stirrup ladder

Fig. 6: Flexible stirrup mat

Fig. 7: Connecting elements: Lenton reinforcing joint
Fig. 8: GEWI method: connection of coupling at the construction joint

Fig. 9: GEWI method: connection of reinforcement at construction joints
   a) bent connecting bar
   b) various anchorage types

Fig. 10: Costs of connecting pieces