REINFORCEMENT WORK ON CONSTRUCTION SITES - A GENERAL STUDY

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This article presents a general production-engineering study of reinforcement work on construction sites. The Swedish reinforcement steel market, the significance of design work from the production viewpoint, the planning and organization of reinforcement work, work methods and equipment, economy and the working environment are dealt with in a general manner in the article. Proposals for measures intended to further develop current reinforcement technology are presented at the end of the article.

Reinforcement, production engineering, economy, working environment.

1. BACKGROUND

Reinforcement is of fundamental importance for the function and safety of a reinforced concrete structure. Because of this, reinforcement and reinforced concrete have been subjected to detailed and extensive research in the field of materials technology and structural engineering.

Research efforts devoted to the production engineering sector have not been anything like as large in scope despite the fact that the production of a reinforced concrete structure often has a major and decisive influence on the quality and economy of the structure.

A glance at current reinforcement technology also shows that developments - at any rate as far as non-tensioned reinforcement is concerned - have remained at a standstill during the last 10-15 years. Reinforcement work is still carried out by means of handicraft methods to a considerable extent, mainly using primitive tools and aids. It is also comparatively labour-intensive, a factor which makes it particularly sensitive to increases in labour costs.

Against this background, a project entitled "Handling Reinforcement" was started at the Swedish Cement and Concrete Research Institute in 1978. The objective for this project was and still is to study reinforcement work with non-tensioned reinforcement on construction sites from the production engineering viewpoint so as to obtain source material for improvements. The term production engineering has been given a broad interpretation in this context and embraces quality aspects, economy and the working environment.

The work began with a general study, /1/, and was followed by in-depth studies in certain important sub-areas. These studies are still in progress.

2. THE ORGANIZATION AND IMPLEMENTATION OF THE GENERAL STUDY

The purpose has been to provide a survey of the reinforcement technology at present in use in Sweden with regard to materials, methods, problems and development needs.

The study has been confined to reinforcement seen from the production engineering viewpoint. Questions connected with materials technology and structural engineering as such have not been dealt with. Nor have special sectors such as welding been included. The general study has mainly consisted of documentary studies and interviews. The documentary studies covered research and investigative reports, statistics, production data etc. Interviews have been carried out with structural engineers, concrete reinforcement workers, supervisors, planners, estimators, site managers and workers in reinforcement shops. A total of some 50 individuals were interviewed.

The study deals with the following aspects:

1. Materials and products
2. The importance of design work from the production viewpoint
3. Planning and organization
4. Work methods and equipment
5. Economy
6. Working environment
7. Research and development needs

Some of the most important results are presented below.

3. MATERIALS AND PRODUCTS

The supply of reinforcement steel to the Swedish construction market dropped drastically during the 1970s, see FIG 1. FIG 1 shows that the supply of reinforcement steel, in other words of traditional reinforcement bars excluding mesh products was practically halved during the 1970s. This is, of course, mainly the result of a reduction in the production of new buildings.

The trend illustrated in FIG 1 has entailed surplus capacity and profitability problems for the Swedish reinforcing steel producers. In addition, competition from imported reinforcement steel has made itself felt.

As a result of this situation the resources available for research and development in the reinforcement steel industry have been limited throughout most of the 1970s. This appears to be one of the reasons for why reinforcement technology has, by and large, remained at a standstill during the last 10-15 years.

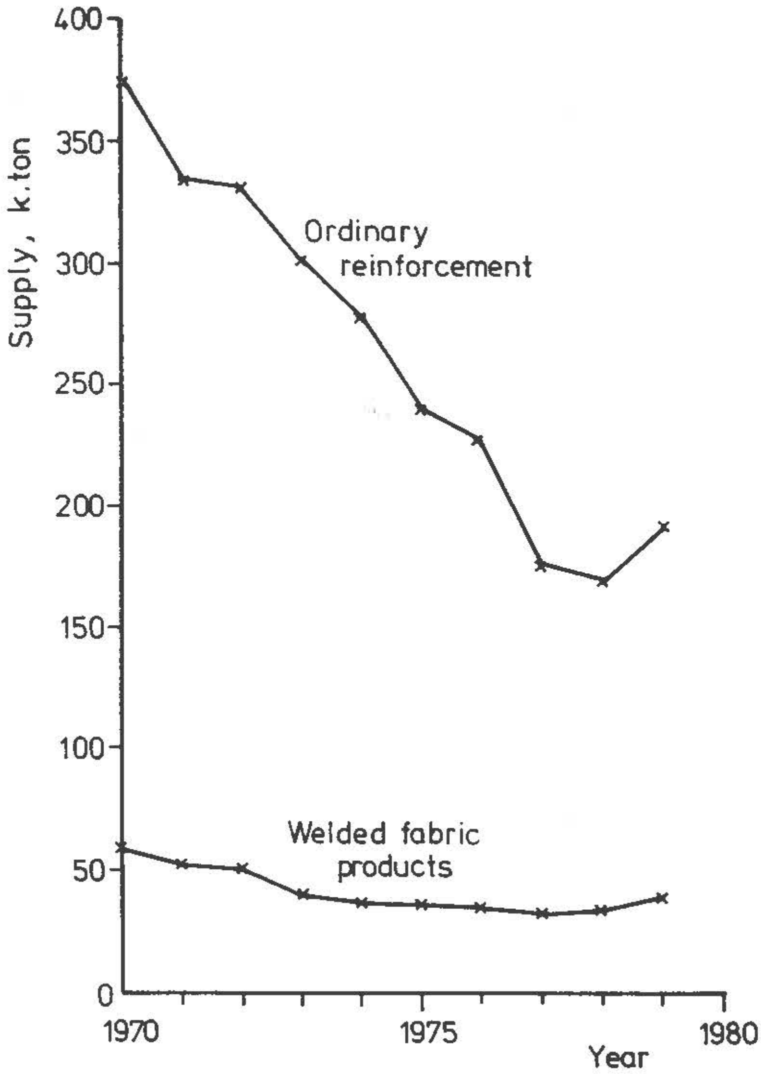


FIG 1. Supply of reinforcement steel and mesh products to the Swedish market.

The following degrees of prefabrication can be used to describe the degree of preparatory work which can be carried out on reinforcement material before it is delivered to a construction site.

1. Reinforcement in stocked lengths. This means that the reinforcement is delivered in lengths of 10-12 m and is then cut and bent on site.

2. Ready cut and ready bent reinforcement. This means that the bars are cut and bent in a reinforcement shop and are, in principle, ready for assembly.

3. Prefabricated units ready for placing in forms. This group includes mesh products and tack welded prefabricated reinforcement cages for columns.

These different degrees of prefabrication represent different levels in the development of reinforcement technology. Consequently, the breakdown of reinforcement material by degree of prefabrication is of interest, see FIG 2.

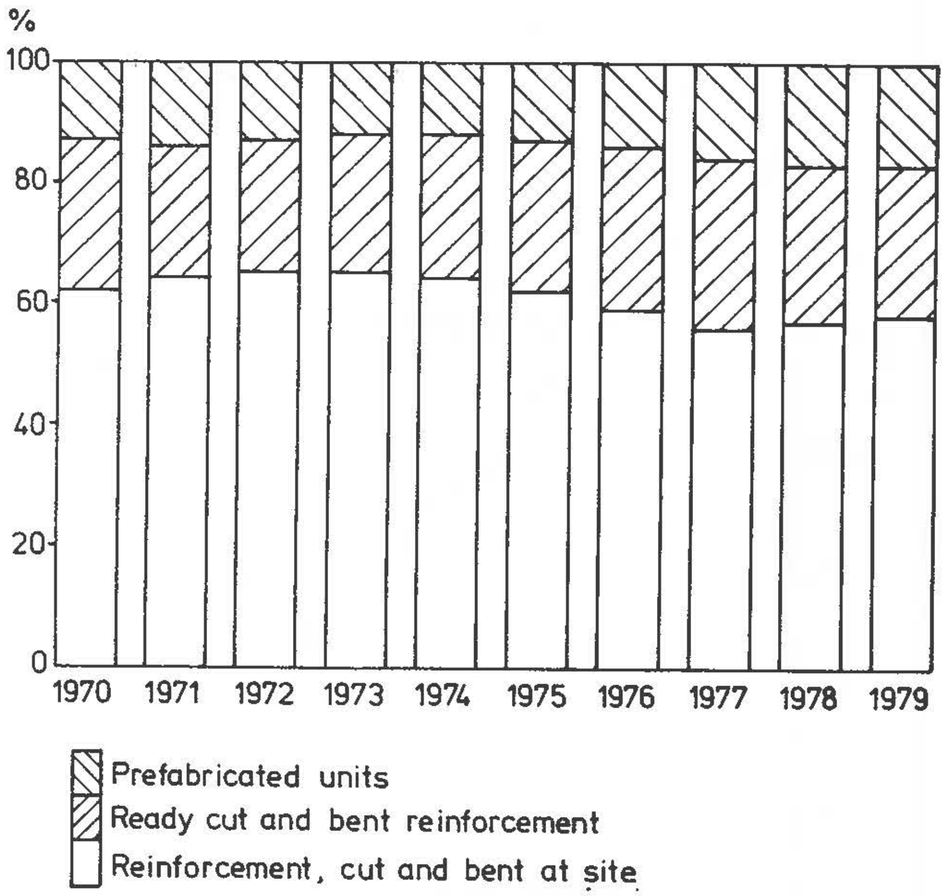


FIG 2. Breakdown by various degrees of prefabrication of reinforcement material supply to the Swedish market.

The following estimate concerning the breakdown of reinforcement material into the three degrees of prefabrication can be made on the basis of FIG 2, which is an estimate based on certain statistics and which applies as an average for the entire country.

1. Reinforcement in stocked lengths, approx. 55%

2. Ready cut and ready bent reinforcement, approx. 25%

3. Prefabricated units (mainly mesh products), approx. 20%

This estimate shows that more than half of all reinforcement is cut and bent on site. The system with ready cut and ready bent reinforcement bars has not by any means become widespread. A number of factors which have influenced this state of affairs are discussed later on in Section 5.

Finally, it can be seen from FIG 2 that there is a weak trend towards a higher degree of prefabrication.

4. THE IMPORTANCE OF DESIGN WORK FROM THE PRODUCTION VIEWPOINT

The interviews which have been carried out with workers, supervisors, site managers etc. have frequently shown that the structural engineer plays a very important part. The manner in which the structural engineer designs the reinforcement is of considerable significance for the reinforcement work, both with regard to economy and the working environment. The reinforcement should be adapted to production and the reinforcement documents should be designed to facilitate reinforcement work. It is quite clear that these conditions need improvement in many cases.

The term production adaptation, as used here, means measures which are taken during the design stage with a view to facilitating reinforcement work on the site. Production adaptation should be oriented towards the optimum overall economy and optimum working environment conditions.

Examples of production adaptation measures have been provided during the interviews, from structural engineers as well as from workers, supervisors etc. Examples which are discussed in /1/ include limiting the number of variants, selecting a suitable type of reinforcement, selecting suitable bar diameters and suitable centre-to-centre spacing, selecting suitable bending types etc. with regard to the necessary manufacturing accuracy and with regard to the assembly work and regard to the subdivision into reinforcement stages.

The structural engineers who were interviewed were generally aware of the importance of production adaptation. During the discussions they pointed out that there are factors which limit and control production adaptation. An unsuitable design of the structure, deficient information concerning production systems and production prerequisites, unclear cost interdependencies and cost consequences, structural engineering requirements and a shortage of time when drawing up reinforcement documents are all examples of factors which can have an inhibiting effect on production adaptation.

The importance of the reinforcement documents was emphasized in conjunction with the interviews on design work. The reinforcement schedule is one document whose importance and significance is often underestimated.

As a result, drawing up a reinforcement schedule has come to be regarded generally as a job with a low status. Lists are sometimes drawn up by inexperienced individuals, frequently resulting in incorrect notations. Errors of this type can give rise to major and serious disturbances in production.

A feedback of experience from the construction site to the design office is essential for satisfactory production adaptation. This was emphasized both by structural engineers and by those working on site.

The structural engineers claimed that this feedback of experience was deficient or non-existent to a considerable extent and that objective criticisms (whether positive or negative) from the viewpoint of execution, economy etc. would be useful.

During interviews with site managers, supervisors, concrete reinforcement workers etc. it was often emphasized that the structural engineer should visit the construction site more frequently than is the case at present.

Visits to the site are also usually regarded as important by the structural engineers. Generally speaking, economic and time limitations do not, however, permit frequent visits. This is particularly true in cases where the site is located at a considerable distance from the engineer's office.

5. PLANNING AND ORGANIZATION

The terms planning and organization are used here in a broad sense and, in conjunction with reinforcement work, are included to cover the choice of degree of prefabrication, the physical planning of the construction site, time scheduling of resources, and work planning. By work planning is meant the planning of the actual reinforcement work with regard to the sequence between the various building components and subprojects, the allocation of tasks within the reinforcement team etc.

The following are the main choices which can occur when selecting the degree of prefabrication:

1. Choice between cutting and bending on site or using ready cut and ready bent reinforcement.

2. Choice between reinforcement with loose bars or reinforcement in the form of prefabricated units manufactured in a reinforcement shop. This situation also embraces the choice between loose bars and mesh products.

A number of different factors can influence these choices which of course, occur in different stages in the reinforcement process, depending on what is involved. Examples include the product type and the design of the structure, the size of the relevant series, the available space, access to manpower, access to skilled manpower, the production system, the production cycles and the viewpoints of the reinforcement team.

Naturally, it is extremely difficult to make fair economic comparisons which take account of all these factors, some of which are difficult or even impossible to quantify. Faced with a situation like this, it is naturally tempting to play safe and use a traditional and accustomed system. This is, in all likelihood, one of the reasons why systems with a higher degree of prefabrication have not been accepted to a greater extent in Sweden, see also Section 3 and FIG 2.

The physical planning of the construction site is important for the reinforcement work when it comes to placing and arranging storage facilities and reinforcement stations.

When layouts are drawn up for construction sites, reinforcement often takes second place. Storage areas which are centrally located and within reach of the crane are reserved for other purposes, for example for receiving - hoppers for concrete, for precast elements etc. One of the reasons for this is that reinforcement can, if necessary, be carried out by hand, whereas this is not possible for heavier products and heavier equipment.

According to /2/ the reinforcement stores are frequently incorrectly planned. Not until a delivery of reinforcement steel arrives at the site is any consideration given to where it should be stored. This results in lengthy transport distances and unnecessary risks of accidents.

The possibilities available for arranging sufficiently large storage sites varies widely from one case to another. The erection of certain central urban buildings constitutes particularly unfavourable cases in this regard since the reinforcement must frequently be stored in different, temporary stores in pace with the progress of the building. This results in frequent transfers and improvisations which, in turn, entail a major risk that the reinforcement marking will be damaged or lost, leading to concomitant identification problems.

What has been said above concerning the storage of reinforcement also applies in certain respects to the reinforcement station. The reinforcement station should be located centrally, adjacent to a store and within reach of the crane. Central location is particularly important when the concrete carcass or frame is being constructed. Reinforcement work is labour-intensive. Consequently, an unsuitable location of the reinforcement station can give rise to considerable lost time due to walking back and forth. Sometimes the reinforcement station is located outside the reach of the crane. This results in an increase in the manual handling of reinforcement steel.

Another problem is that very little space often remains for reinforcement work and the reinforcement station. This can reduce the possibilities available for building up the reinforcement station in such a way that it receives a rational and suitable design. This can, in turn, entail increased handling time and unsuitable ergonomic conditions.

6. WORK METHODS AND EQUIPMENT

The handling of reinforcement on a construction site can, in principle, be subdivided into main operations and suboperations as illustrated in FIG 3.

The occurrence, scope and importance of the various suboperations can vary within wide limits depending on factors such as the design of the structure, the degree of prefabrication used, the organization and appearance of the site, and the design of the reinforcement station.

The suboperations which require most time and which are, consequently, of primary interest, consist of cutting, bending, prefabrication units on site and placing.

PHASE	OPERATION	NO.
RECEPTION	UNLOADING	1
	SORTING, PUTTING UP	2
PREPARATION	TRANSPORT TO CUTTING MACHINE	3
	CUTTING	4
	TRANSPORT TO BENDING MACHINE	5
	BENDING	6
	BUNDLING, MARKING	7
	TRANSPORT TO STORAGE	8
ASSEMBLY	PREFABRICATION OF REINFORCEMENTUNITS AT SITE	9
	TRANSPORT	10
	PLACING	11

FIG 3. Reinforcement work on construction sites. Main operations and suboperations. Schematic figure.

The cutting and bending work is, of course, influenced to a considerable extent by the design and equipment of the reinforcement station.

The design of the reinforcement station varies markedly from one construction site to another. Variations include the design of the preliminary store, the working heights for cutting and bending, the working base, wind and rain protection, and lighting. The reinforcement station illustrated in FIG 4 is, however, fairly typical. The preliminary store, roller conveyor and cutting machine are located at ground level, thus giving rise to taxing work in unsuitable work postures. There are no wind or rain shelters.

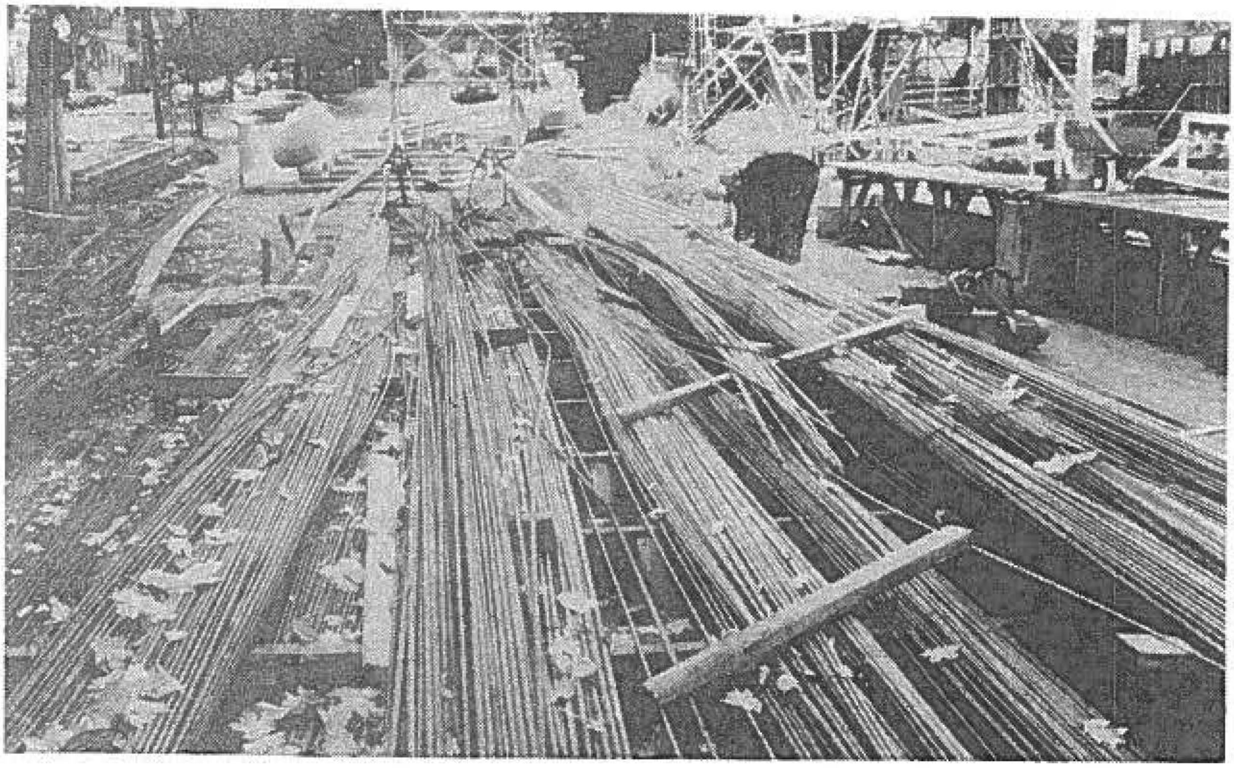


FIG 4. Reinforcement station of traditional type.

The design of the reinforcement station is of considerable importance for the working environment situation during the preparatory stage. Working heights, access to roller conveyors and the design of the preliminary stores constitute examples of factors of major importance. A prefabricated reinforcement station, which has been designed to meet ergonomic requirements and which takes the abovementioned factors into consideration, is sold on the Swedish market. Unfortunately this reinforcement station is used to no more than a very modest extent, but appears to be gaining in popularity, particulary on large-scale construction sites.

During the assembly stage, cf. FIG 3, attempts are generally made to manufacture units outside the form. The possibility of doing so varies from one building component to another and from one project to another. This procedure, which is commonly adopted for columns, beams, edge beams and the like but which is unusual for floor constructions, slabs and walls, makes it possible to avoid troublesome work postures, at the same time as the tasks involved can be used to level out the work load.

A description of the assembly and placing methods used for reinforcement in the most commonly occurring building components is provided in /4/ and /5/. This description applies mainly to buildings but is general in certain regards.

The investigations presented in /4/ were carried out as a result of the fact that measurements made of the actual position of reinforcement in structures have shown major deviations from the intended positions, see /3/.

The investigations showed that the reasons for the deviations between the actual and the intended positions included the following: poor dimensional accuracy in the reinforcement material, unsuitable assembly methods, unsuitable design of the structure and careless concreting methods.

Certain wishes for future developments are presented in /4/ against the background of what has been related above. These consist of:

1. Improving methods for assembling and placing reinforcement

2. Improving reinforcement systems from the production viewpoint

Developments during the 1970s have not, however, fulfilled these wishes. The methods used for assembling and placing reinforcement have not been changed to any noteworthy degree. Nor have reinforcement systems been improved from the production viewpoint. On the contrary, the 1970s have entailed a certain regression in this regard. This is true of, for example, the use of prefabricated units in the forms of tied mesh top reinforcement and top reinforcement stirrups. These products, which were developed during the 1960s, offer numerous production engineering advantages. Their use has, however, gradually decreased during the 1970s, partly due to changes in project type and reduced series sizes.

Most of the tools and aids used in connection with assembling reinforcement are simple and primitive. Consequently, there is considerable need of and room for development and innovation in this sector.

7. ECONOMY

The following is no more than a general presentation of the economy of reinforcement and reinforcement work. For a more detailed discussion, see /1/. The following aspects are dealt with:

1. Reinforcement costs as a percentage of the overall cost for a concrete structure

2. Contributory factors

3. Cost allocation

4. Cost and productivity trend

TABLE 1 provides a compilation of certain information taken from the literature concerning reinforcement costs as a percentage of the overall cost for a concrete structure.

TABLE 1. Reinforcement costs as a percentage of the overall costs for a concrete structure.

Source	Approximate percentage	Comments
Concrete Society /6/	25-30	"Normal" structures
Nilsson /7/	15	"Simple", non-tensioned bridges /1976/
Bellander /8/	20	
CEB /9/	25	Utility buildings

Note: The overall cost includes costs for formwork, reinforcement, casting and subsequent treatment.

It can thus be seen that reinforcement costs amount to about 20% of the overall costs. Considerable deviations from this value can, however, occur in practice, as can be seen from the table, the reason being that a very large number of factors influence the cost pattern. These factors can be broken down into primary and secondary factors.

The primary factors can be regarded as the prerequisites on which the design, planning and execution of the reinforcement in a concrete structure are based. The secondary factors can be regarded as deriving from measures taken as a result of these prerequisites. The secondary factors are thus dependent on the primary factors, but can also affect each other in certain cases.

The following factors are probably the most important:

Primary: Series size, project type, appearance and design of construction site, overall planning and organization.

Secondary: Reinforcement type, bar diameter, design of structure, degree of prefabrication, physical planning, resources and work methods on the construction site.

Another factor, which cannot be directly referred to either of the above groups but which can be of major significance, is the question of disturbances.

Costs for the reinforcement in a concrete structure can, in principle, be broken down according to FIG 5. The following two cost subdivisions will be dealt with briefly below, in accordance with the structure of this figure:

1. The subdivision of the overall cost into material cost and handling cost

2. The subdivision of the handling cost into various handling operations

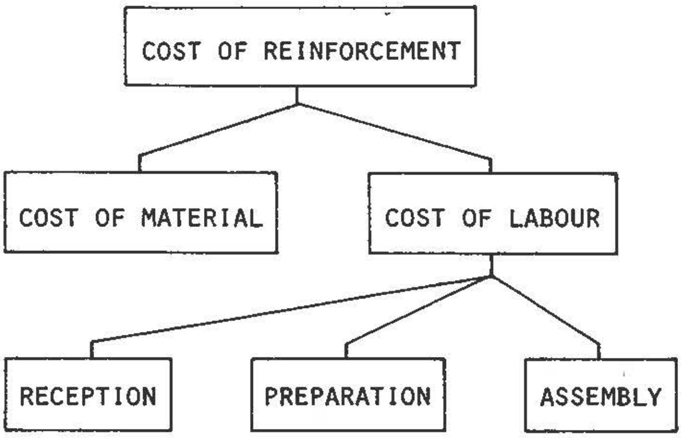


FIG 5. Breakdown of reinforcement costs. Schematic figure. Note: The material cost includes the costs of transporting the material to the construction site.

The subdivision into material costs and handling costs is influenced by several factors. The degree of prefabrication, the building component in question and the design of the structure are probably amongst the most important of these. The subdivision can thus vary within wide limits. At present, material costs and handling costs are probably roughly equal in many cases.

A breakdown of the reinforcement work on a construction site into main operations and suboperations has been made in Section 6, FIG 3. As was pointed out in this section, the occurrence, scope and importance of the different suboperations can vary from one case to another.

Because of this, the breakdown of handling costs amongst various operations can also vary within wide limits. An estimate in accordance with TABLE 2 can, however, be made on the basis of available information in the literature and available production data.

TABLE 2. Breakdown of handling costs by various main operations. Estimate

Main operations	%
Reception	0-5%
Preparation	25-50
Assembly	50-75

The following aspects are of interest with regard to developments and development trends:

1. Productivity trend

2. Development of relation between material costs and handling costs

Productivity in the Swedish construction industry has, for the most part, shown a downward trend for the last 5-7 years.

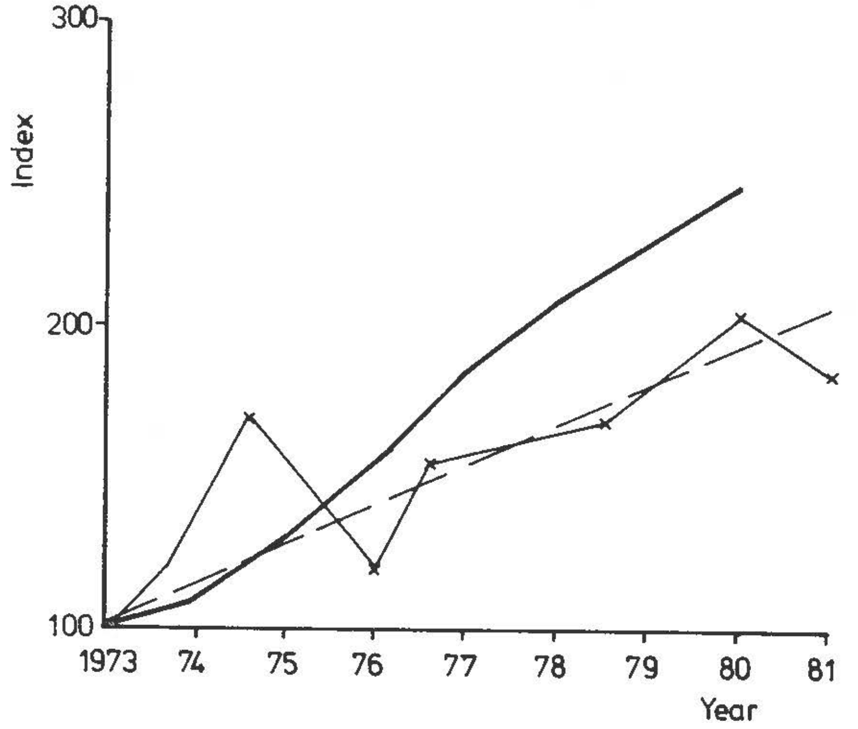
Reinforcement work on construction sites has not constituted an exception in this regard. According to information obtained from several sources, the time required for reinforcement work has increased markedly, particularly in recent years. The following have been mentioned as some of the reasons for the impaired productivity in reinforcement work.

- Smaller project sizes and smaller series

- Project type and project design. The richness in variation which characterized some of the building projects during the 1970s made production adaptation more difficult and thus impaired productivity.

An idea of how the relation between material costs and handling costs developed during the 1970s can be obtained from FIG 6. This figure shows - for the period 1973-1981 - the index for the basic price for reinforcement steel and the index for the hourly cost for reinforcement workers. It can be seen from the figure the hourly cost has, as a whole, increased more rapidly during this period than has the basic price for reinforcement steel. The supplements (dimensional supplement, quality supplement, etc.) which are included in the price-setting system applied by the steel mills have, by and large, been developed at the same rate as in the basic price. In other words, the curve shown for the basic price in FIG 6 reflects in a fairly accurate manner the development of material costs.

It can thus be seen from FIG 6 that the hourly cost has risen and is still rising more rapidly than the material cost. As a result of this, and as a result of the productivity trend which was dealt with above, handling costs have been and continue to be responsible for an increasingly large share of the overall cost.



—— BASIC PRICE FOR REINFORCEMENT, DELIVERED FROM SWEDISH MANUFACTURERS AFFILIATED TO BASTA

—— HOURLY COST FOR REINFORCEMENT WORKERS (HOURLY WAGE + ADDITIONAL WAGE COSTS, HOLIDAY WAGE EXCLUDED) SOURCE: FEDERATION OF SWEDISH BUILDING EMPLOYERS.

FIG 6. Index during the period 1973-1980 for the basic price for reinforcement steel and for the hourly cost for reinforcement workers.

8. WORKING ENVIRONMENT

The term working environment covers everything that surrounds, and influences man in his work: the actual task, the machinery, aids and materials used, the design and climate of the workplace, the relationships amongst those working there etc. Some of these aspects are dealt with below in accordance with the following structure:

1. Physiological work load - laborious operations

2. Work postures

3. Risks of accidents

4. Industrial injuries - state of health

5. Contentment factors - psychological working environment

The operations which are regarded as most laborious consist of lifting and carrying reinforcement steel. These operations occur regularly throughout the entire reinforcement process on a construction site. They become particularly large in scope when the reinforcement is cut and bent on site.

It also occurs during the assembly stage that reinforcement is carried manually from the store at the reinforcement station to the placing point, due to the fact that the crane is occupied on other work or to the fact that the reinforcement station has been located out of reach of the crane.

Reinforcement work embraces a number of uncomfortable work postures. FIG 7 shows work in a work posture which entails bending forward. This work posture is extremely common in connection with the assembly of floor reinforcement and the like and it subjects the back to considerable strain.

The accident risks which are regarded as the most serious by concrete reinforcement workers are risks of stumbling and slipping.

The risk of stumbling is particularly great when working with and on top of reinforcement. The risk of slipping is great in connection with, for example, reinforcement work on recently oiled shutter trestles.

Other accident risks include cut-off tying wires, projecting reinforcement rods, projecting form ties, and the risk of falling due to insufficient protective measures.

As far as the state of health of concrete reinforcement workers is concerned, statistics and investigations show that back problems are extremely common amongst this category of worker. Load factors which can be assumed to be particularly trying and damaging for backs are:

1. Lengthy periods of work leaning forwards or bent forwards; this entails a static load.

2. Certain dynamic loads which incorporate risks of further, sudden loads on the back, for example slipping and stumbling when carrying heavy burdens.

The psychological working environment should, like the physical working environment, meet certain requirements. Responsibility, independence, variation, stimulation, esteem and respect are some of the factors which are important from the individual's viewpoint.

Many of these needs are, in fact, fulfilled to a considerable extent in reinforcement work. This is particularly true of the team foreman. Reinforcement work is characterized by the fact that:

- o the foreman bears responsibility for planning and organizing the work,
- o reinforcement work requires an intellectual effort in the form of, for example, reading drawings,
- o the work is comparatively variegated
- o the work has a comparatively high status since it requires both craftmanship and technical expertise.

These factors are respected in the attitude which concrete reinforcement workers adopt with regard to their work. The workers who were interviewed generally experience their work as stimulating, variegated and meaningful.

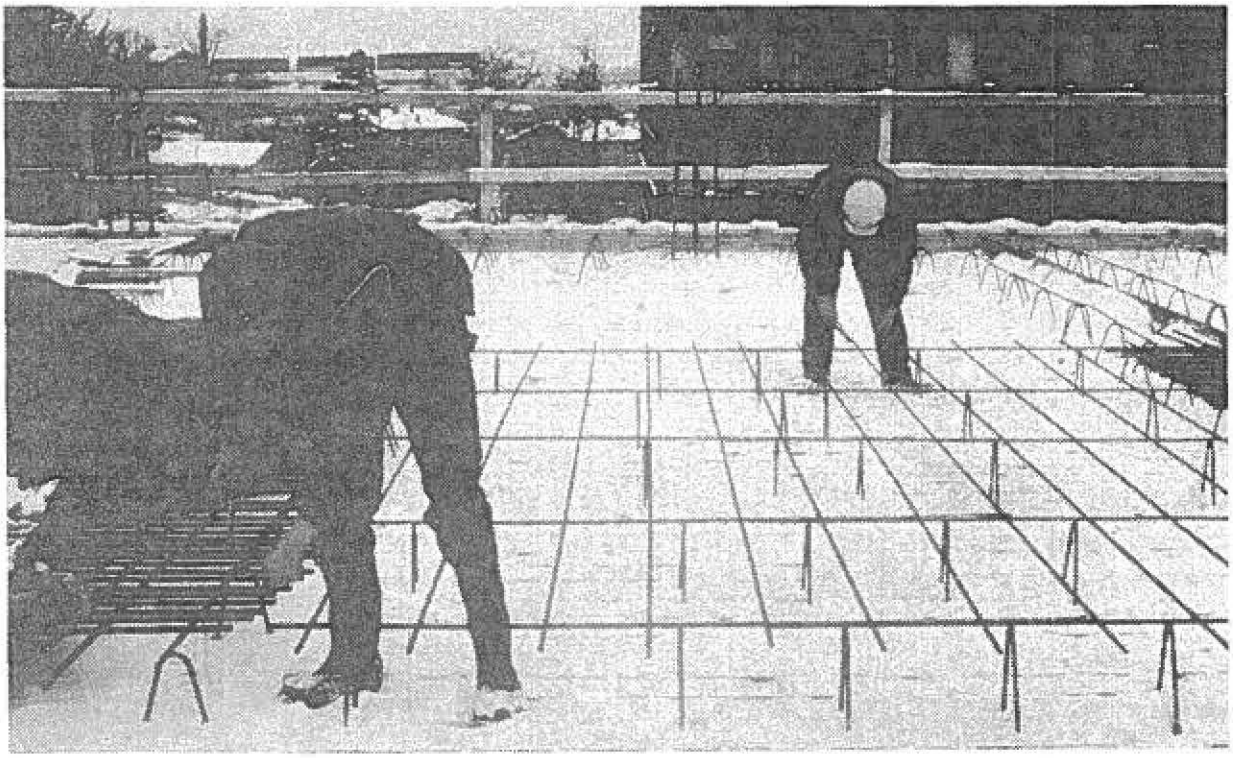


FIG 7. Forward bending work posture.

9. RESEARCH AND DEVELOPMENT NEEDS

What has been said in the preceding sections indicates clearly that there is considerable need of improvement in current reinforcement technology. This applies both from the economic and the working environment viewpoints.

Such improvements require actions, actions on different levels with different orientations and with different scopes. The actions taken must vary in character, consisting mainly of research work but also work with the emphasis on development, information and training. The following examples are worth mentioning:

1. Simplification of reinforcement

Current reinforcement needs to be simplified in many ways. One of the reasons is that calculation methods have been refined and can result in complicated reinforcement with poor production adaptation, causing time-consuming and troublesome work procedures.

2. Development of reinforcement systems and reinforcement products

Current reinforcement technology consists, to a considerable extent, of manual work. In the long term, the aim should be to increase the degree of prefabrication of the reinforcement. This objective requires, in turn, the development of reinforcement systems and reinforcement products to make it possible. A development of this type should be aimed at improving reinforcement from the economic and working environment viewpoints.

3. Systematized collection of experience from executed reinforcement work

The importance of feeding back experience has been emphasized in Section 4. A systematized collection of experience data from reinforcement work which has been carried out should include the collection of production data for various projects. Guidelines for functional and rational design work can then be drawn up on the basis of an analysis of the collected production data with regard to the reinforcement type, the design of the structure, the degree of prefabrication etc.

4. Broadening tuition at the institute of technology and the upper secondary schools

The tuition provided today on reinforced concrete in building construction courses at the institute of technology is mainly confined to basic static engineering. Bearing in mind the considerable importance of design work for the economy of reinforcement and for the working environment involved, this tuition should be broadened to include production engineering issues connected with reinforcement, for example the choice of reinforcement system, production adaptation and economic evaluations of various systems.

5. Development of tools, aids and equipment

Many of the tools and aids used in reinforcement work are simple and primitive. This is particularly true of the tools used for assembly work. Such tools often give rise to unsuitable ergonomic conditions, at the same time as the technical result can be unsatisfactory in certain cases. Against this background, new tools and aids and new equipment should be developed.

A feature which is common to all these actions is that they should contribute to improving reinforcement from the production engineering viewpoint, in other words to improving the economy and the working environment. This may only take place within the framework for what basic technical quality, functional and safety requirements permit.

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