SYNTHESIS REPORT

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TITLE: Integrated Production Cell for the Steel Components of Reinforced Concrete Building Elements - InProRos

PROJECT COORDINATOR: BMT Ltd.

PARTNERS:
BMT Ltd.
Ergon S.A.
Girobo
House S.A.
Spanbeton B.V.

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INTEGRATED PRODUCTION CELL FOR THE STEEL COMPONENTS OF REINFORCED CONCRETE BUILDING ELEMENTS (INPROROS)

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ABSTRACT

The InProRos project was a three year research project conducted under the Brite-EuRam programme, which has attempted to address the competitiveness of the pre-cast industry by researching reinforcement production machinery together with the concept of a flexible reinforcement production cell.

A pilot plant has been set up at the Koudekerk factory of Spanbeton B.V. The machinery for the pilot plant consists of a stirrup bender, a novel 2D stirrup assembler (for the welding of 2-3 stirrups into a 2D assembly), and a 3D cage welding installation comprising a standard industrial 6-axis robot arm equipped with a welding torch and two servo-driven turntables. Specific sensoring tools and software modules have been developed for this unique application. Considerable operational testing and evaluation of the machinery in the pilot plant has been carried out.

Machinery concerned with other ‘aspects of the reinforcement industry has also been developed. These developments include a flexible 2D mesh welding machine, the design work on a large diameter stirrup bender, based on servo-hydraulic technology, and capable of working with wire up to 22mm in diameter, and a 3D panel integrating machine (a machine that produces panels consisting of insulation sandwiched between two reinforcement meshes). A working prototype of this machine has been developed and implemented. Research on this machine has concentrated on the welding sub-systems, the feeding mechanism for the meshes and insulating material and the collection mechanism for the completed 3D panels.

Control software has been developed for the pilot plant to manage the information flow through the reinforcement workshop. The software includes product definition and scheduling facilities, and is capable of transferring data to machinery in the cell. The software has a spreadsheet style of interface, and is highly configurable to enable it to be adapted to the changing needs of such a reinforcement cell.

In the pilot plant, productivity improvements over the previous manual operation of factor of -3 and -2 have been registered for the stirrup bender and the robotic 3D cage welder respectively. The 3D robot has been a great success, and continuous improvements have been made in product adaptation, jig design, programming techniques and welding techniques.

INTRODUCTION

Reinforcement workshops in the pre-cast industry in Europe are usually relatively small production units, and the wide variety of products has kept production labour-intensive and arduous. Productivity has stagnated for a decade and the job description does not tempt skilled workers. InProRos, a three year research project conducted under the Brite-EuRam programme, has attempted to address the competitiveness of this industry by researching reinforcement production machinery together with the concept of a flexible reinforcement production cell.

The primary objective of the project was to research and develop a prototype hardware and software environment for the integrated production of the steel components of reinforced concrete elements. This overall objective was subdivided into the following more specific objectives: the development of the concept of a flexible production system within a reinforcement workshop, bringing together existing machinery, novel machinery, and a computerised information management and control system; the development of reinforcement processing machinery and machinery concepts, involving both specific hardware sub-systems and complete machines, concentrating on machinery for reinforcement assembly; the development of hardware sub-systems for a sandwich integrating machine (a machine that produces panels consisting of insulation sandwiched between two reinforcement meshes); the development of software for the control and operation of a reinforcement production cell as a heterogeneous set of machines and work stations; and the development of the interface between the control system and the low-level controllers of the various machines in the cell.

Five companies from four European countries undertook the project: BMT Ltd. (UK); Ergon S.A. (GR); Girobo (F); House S.A. (GR); and Spanbeton B.V. (NL).

TECHNICAL DESCRIPTION

REQUIREMENTS

No revolutionary progress was foreseen in reinforcement production without a wide approach, combining efficient product modelling, standardisation, smooth data flow and modern CNC-controlled machinery. From a commercial point of view, a vital factor for competitiveness is the overall increase of productivity and shortening of through-put and lead times in all stages of reinforcement production.

The demands of flexibility together with low volumes, set difficulties when the cost-benefit equation was solved for the InProRos concept. The market in general lacked machinery adapted to the pre-cast business environment. However, possibilities were foreseen: the availability of 16 and 20rnm diameter reinforcement in coils would facilitate the automated processing of these diameters; CNC-controlled mesh welding machines would allow the production of individual meshes, achieving significant material savings; the availability of general purpose 6-axis robots with their inherent flexibility would enable automation to be considered for tasks previously considered uneconomic to automate.

The fundamental requirement for the pre-cast industry was found to be flexibility of manufacturing, leading to the concept of a widely integrated reinforcement production cell. This concept could be elaborated as follows:

- Full data integration from design to production, including design for automation and the use of a 3D product model for reinforcement.
- A comprehensive cell control system that can process all the reinforcement used in a factory.
- CNC machinery linked to the cell control system:
  - A 2D stirrup bender (max. wire diameter preferably 16 mm).
  - A 2D stirrup assembler (XY table 1.7m x 1.2m).
  - A 3D cage welder.
  - A 2½D mesh welder (or a 2D mesh welder and a mesh bender).
- Appropriate materials handling at machines and materials flow between machines to maintain flexibility.

PILOT PLANT MACHINERY

The pilot plant was located in the factory of Spanbeton B.V. at Koudekerk in the Netherlands. The main production of reinforcement here is for pre-stressed beams and columns. The requirements were therefore refined to specify the machinery of the cell as a stirrup bender, a novel 2D stirrup assembler, and an industrial robot for 3D cage welding.

Stirrup benders were "state of the art" in reinforcement processing machinery prior to the project. The output of the stirrup bender is the input for the following assembly stages, and the quality is therefore of crucial importance. Inaccuracies in stirrup production cause most of the difficulties encountered in the succeeding stages. While in comparison with manual bending the accuracy is improved, nevertheless, the accuracy is not too good. The inaccuracies arise from the raw material: the coils of steel wire vary from metre to metre. Although other conditions remain the same, relatively wide inaccuracies still occur in terms of planar and bending angle distortions. It is envisaged that no revolutionary accuracy improvements are foreseen even if other raw material suppliers or stirrup bender supplier are used. This means an emphasis on jigs and clamping tools for the following stages.

2D Stirrup Assembler

The 2D stirrup assembler is a novel machine developed within the project. The machine is designed to weld together simple units consisting of bent and cut stirrups produced by hand or by an automatic stirrup bender. A "typical" assembly might consist of 3 stirrups, requiring 5 welds. The products of the machine occur in two contexts within normal production at the factory. One context is the assemblies that are placed transversely at intervals along a beam or column. The other context is 2D sub-components of 3D end or corbel cages. The 2D stirrup assembler is therefore targeted at the most labour-intensive task in the reinforcement workshop.

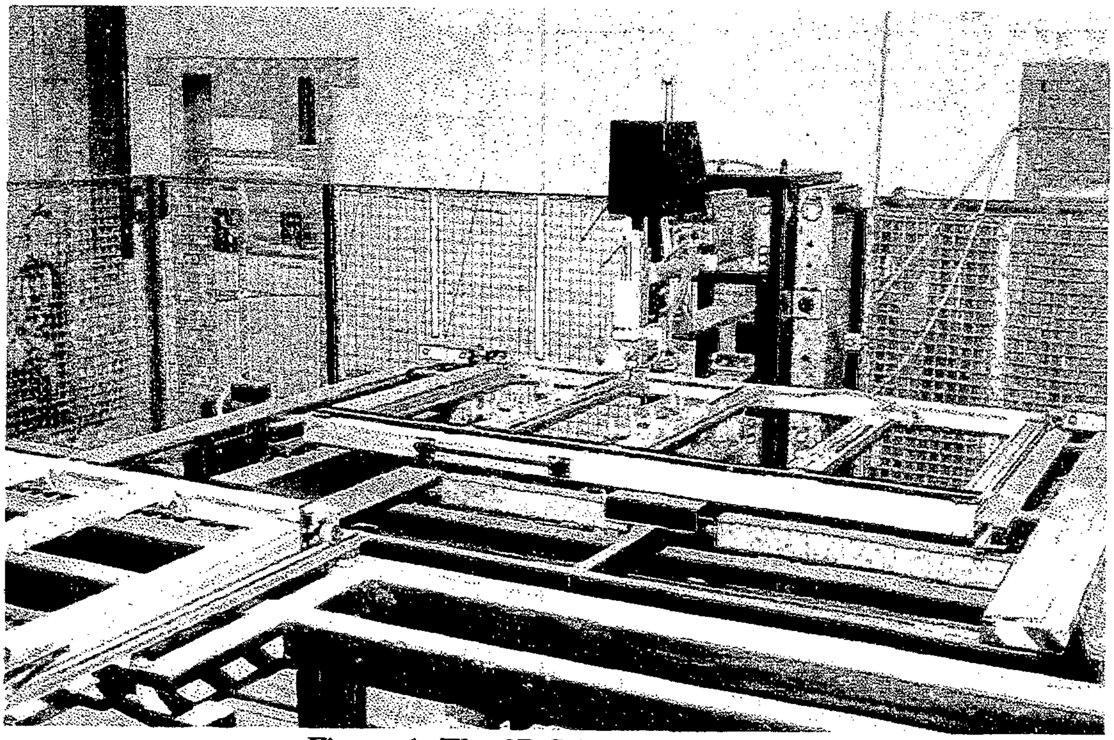

Figure 1: The 2D Stirrup Assembler

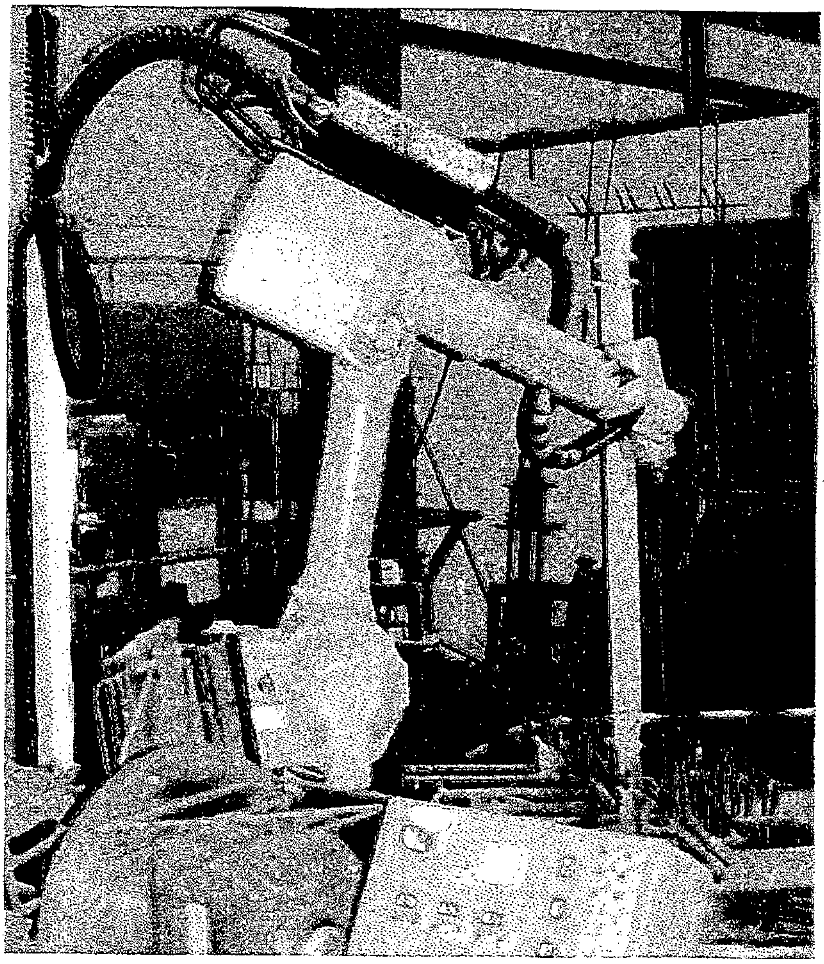

Figure 2: The 3D Cage Welder

The concept and control of this new type of machine was designed by Spanbeton. The structure is based on a standard spot welder and a servo-driven XY-coordinate table. The machine is able to weld on an area of 1.2 x 2.0 m^2. The assemblies can have welding points at any desired location within this area. Positioning accuracy is better than 1.0 mm. The welding is done by a programmable spot-welder, programmed according to the relevant diameter combinations.

The 2D stirrup assembler has two welding tables. These two tables enable a continuous work cycle to be performed: one table is unloaded and reloaded, while the assemblies on the other are welded. Each welding table has an adjustable jig comprising four bars with four holders each. The stirrups to be welded are held in these holders or in product specific jigs attached to the table. The machine is illustrated in figure 1.

3D Cage Welder

In looking at machinery for 3D cage welding, following comprehensive analysis it became clear that the required flexibility, attainable machine properties and available budget could never meet. Therefore the consortium took a different approach: how far could be reached by applying the presently available robotics to new areas? The solution for 3D cage welding - a standard 6-axis robot with peripheral positioners and equipment - was seen as the best choice because of the flexibility, built-in properties and future application possibilities.

The robot cell configuration was designed by Spanbeton. The design was preceded by an extensive market survey. In addition to this, the work envelope, the type and location of the peripheral positioners as well as various robot types were evaluated inter alia with a help of an extensive simulation programme called IGRIP. The designed concept was proved, when Spanbeton rented an experimental production unit in Finland and performed a set of tests. The objective of these tests was to get realistic answers to the question of whether a standard industrial 6-axis robot with adequate positioners is suitable for welding 3D reinforcement cages. The results of these tests concluded that the concept was feasible.

The robot was ordered, and initially installed in an isolated part of the factory, and following the start-up period, it was moved from the separate experimental workshop to the actual production line. This took place due to a request of the workers, indicating a wide acceptance of the newcomer. The robot has received considerable attention from the end-users, and has benefited in the form of numerous small technical improvements, including work process progress, product adaptation and jig construction, The peripherals, especially the clamping tools, have received enhancements “which bring more safety, efficiency and ease of use for the user. The robot is illustrated in figure 2.

In order to better cope with inaccuracies and deformations, Spanbeton developed a specific touch sensor and a set of search and compensation routines. The sensor is attached to the welding nozzle. It has two planes (X and Y axis) that give a signal when the sensor touches the searched rebar. The Z axis is controlled through the welding wire. The search routine programmed can manage all search functions starting from linear search up to real three-dimensional searches (3 translations and 3 rotations). These search programmed are available for the user as library functions and they can be applied anywhere in the robot's work envelope. The true 3D search function is practical also when the jig is placed on another place or positioner: the original welding programme can be put inside such a compensation frame.

A decomposition of 3D cages to smaller repetitive, preferably 2D elements is the key for success. These units can be produced very effectively as the jig construction is simplified considerably. A number of 2D products (10 - 15) can be stacked on one jig and welded with one pass of the robot. This makes the robot a very effective competitor for welding the stirrup assemblies for which the 2D assembler was designed. Some two thirds of the products passing the robot cell are reduced to 2D form. This illustrates the benefits of design for automation.

With selected products, productivity improvement of even 100'ZO can be registered. The right selection is here essential: the stirrups get deformations during the welding process and the jigs must support the composition from right directions, without hindering the removal of the ready product. Close communication is crucial between the engineering office, stirrup bender operator, jig constructor and the robot operator in order to adapt the product and the process in an optimised way.

REINFORCEMENT MACHINERY

Machinery concerned with other aspects of the reinforcement industry has also been developed. These developments include a flexible 2D mesh welding machine, the design work on a large diameter stirrup bender, based on servo-hydraulic technology, and capable of working with wire up to 22mm in diameter, and a 3D panel integrating machine (a machine that produces panels consisting of insulation sandwiched between two reinforcement meshes).

3D Panel Integrating Machine

A working prototype of a 3D panel integrating machine has been developed and implemented. Research on this machine has concentrated on the welding sub-systems, the feeding mechanism for the meshes and insulating material and the collection mechanism for the completed 3D panels. The machine layout is illustrated in figure 3.

In the initial prototype, the welding system was developed. This welds a range of oblique connecting wires in each transversal position of the mesh, so that the two wire meshes are connected. The machine has the capability to include an insulating material between the meshes. Following the successful operation of the prototype, the machine was enhanced by the addition of an automatic feeder for meshes and an automatic product delivery and removal system. The two sub-systems and their place in the complete concept is illustrated in figure 3. The construction of the two mechanisms was completed and a pilot operation was carried out for two months. The integration of both mechanisms to the production line for 3D panels resulted in an overall increase in productivity of 20% and a decrease in the involved personnel of 40%. The quality of the panels was also improved.

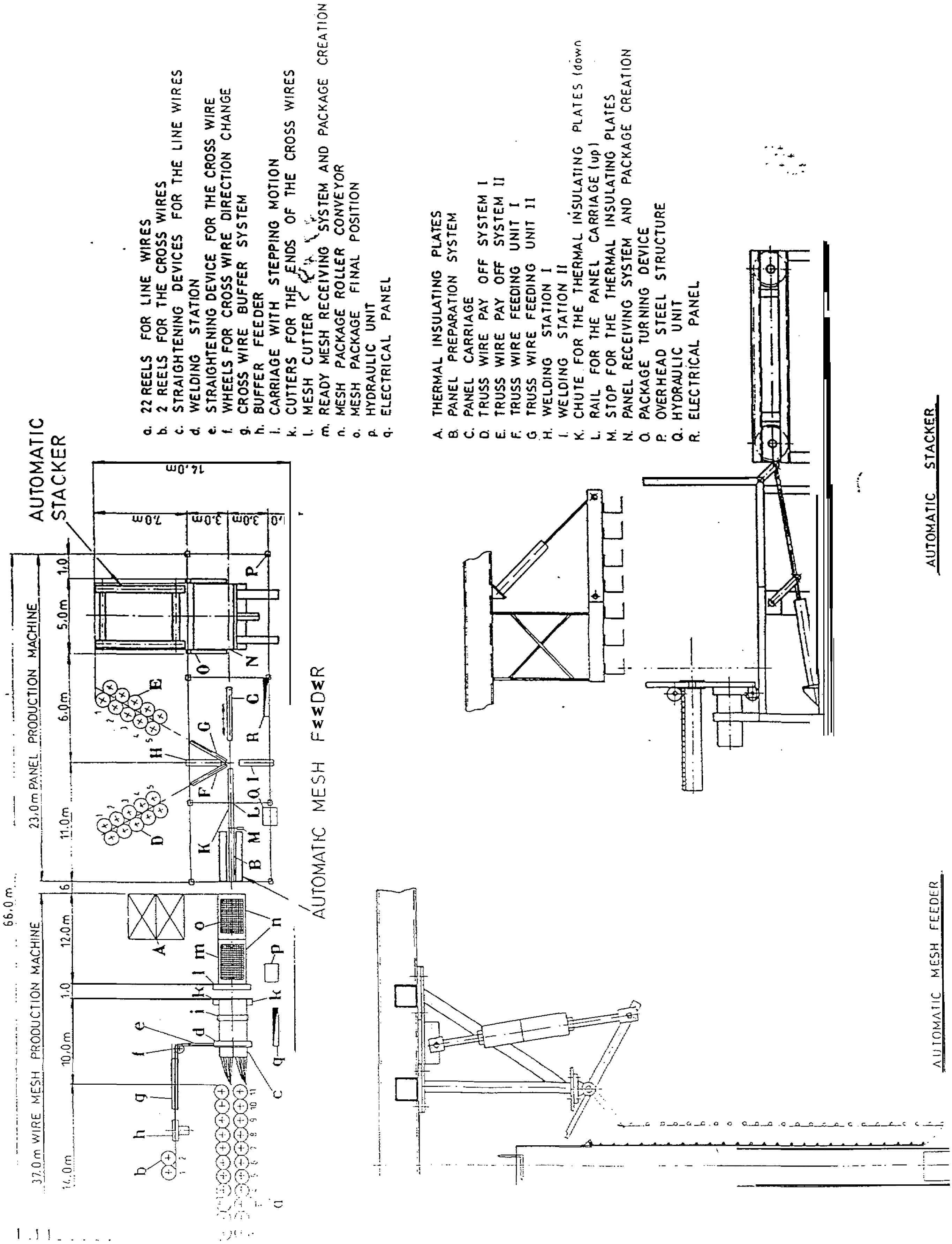

Figure 3: Layout of the 3D Panel Integrating Machine

CONTROL SYSTEM

Control software has been developed for the pilot plant to manage the 'information flow through the reinforcement workshop. The software includes product definition and scheduling facilities, and is capable of transferring data to machinery in the cell. The software has a sophisticated spreadsheet style of interface, and is highly configurable to enable it to be adapted to the changing needs of such a reinforcement cell. The development can be divided into two main phases, stage A and stage B. In stage A, the objective was to develop the minimum necessary to demonstrate the complete flow of information from product definition to the making of that product by a machine in the cell. In stage B, the objective was to develop a system that would satisfy the operational requirements of the pilot plant.

The centre of the system is the reinforcement editor, which enables the user to edit lists of stirrups, as part of product definition or schedule definition. The list of stirrups is presented in a spreadsheet format, with a graphical display of the current stirrup. The reinforcement editor is illustrated in figure 4.

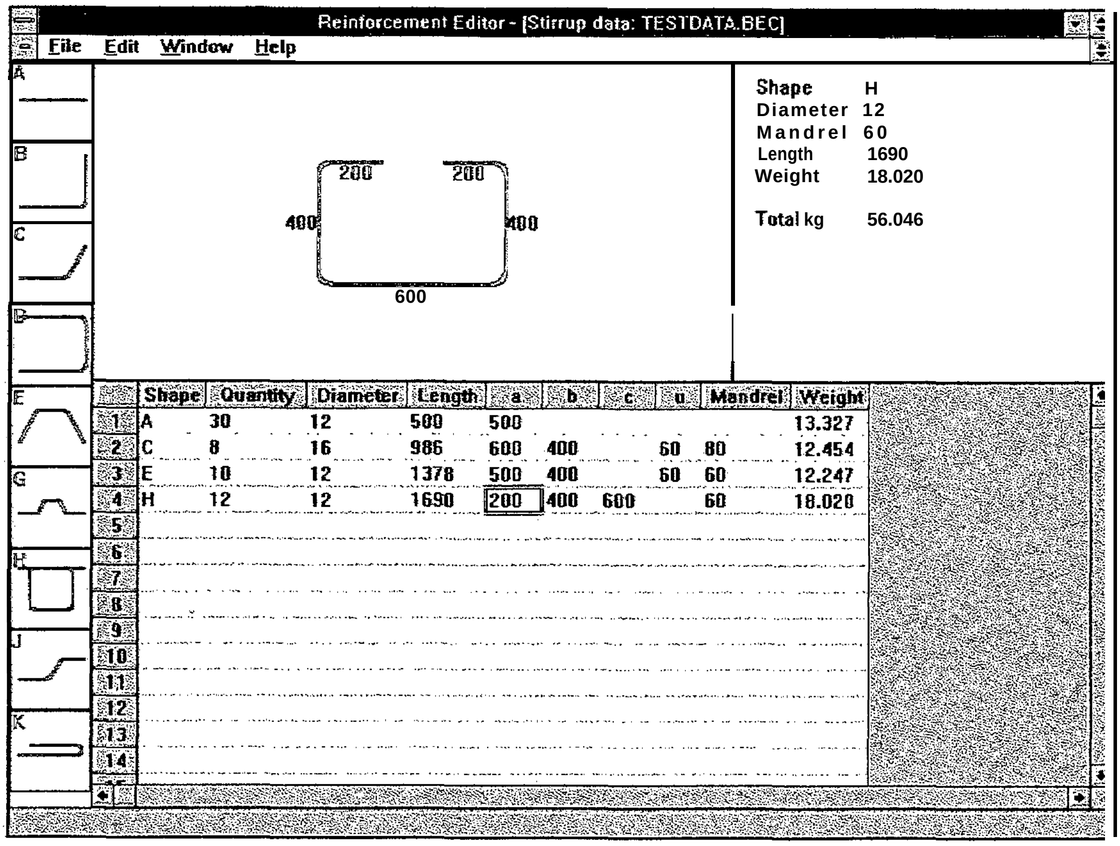

Figure 4: The Reinforcement Editor.

RESULTS & CONCLUSIONS

The project has generated the following results:

- A pilot plant, in the reinforcement workshop of Spanbeton B.V., which operates as an integrated production cell. The pilot plant exhibits an overall 40% improvement in productivity.
- The application of a six-axis industrial robot to the assembly (i.e. welding) of 2D and 3D reinforcement components.
- A 2D stirrup assembly machine.
- A "sandwich" machine for the production of 3D mesh panels, consisting of a slab of insulation sandwiched between two meshes.
- A flexible 2D mesh welding machine.
- Control software for the management of a reinforcement workshop as an integrated production cell.
- Communication software for the interface between the control software and machines in a reinforcement production cell.

ACKNOWLEDGEMENTS

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