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# Integrated Bridge Design with Applied CAE

Conception assistée par ordinateur pour le projet de pont

Ein CAD-System für den integrierten Brückenentwurf

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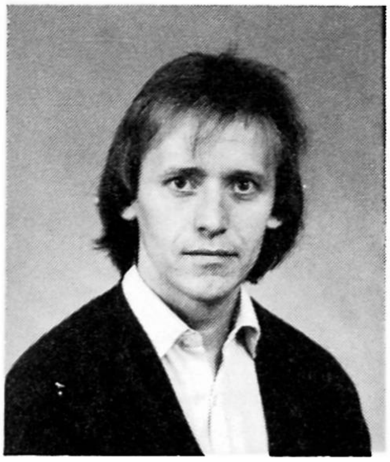

Leif Andersson, born in 1954 received his MSc in Civil Engineering and his PhD at the Royal Institute of Technology, Stockholm. His main interest has been research and industrial applications in conjunction with risk analysis and the finite element method. Leif Andersson is at present in charge of software development at NordCad.

**SUMMARY**
The paper presents a CAE system for integrated bridge design. The system consists of a number of integrated modules, for instance finite element analysis, reinforcement calculation, and CAD interface modules. For an input of approximately 1–2 pages of data, the system will produce more than 15 working drawings apart from graphical print-outs and lists of output data.

**RÉSUMÉ**
L'article présente un système de conception assistée par ordinateur pour le projet intégré de pont. Le système contient un nombre de modules intégrés, par exemple l'analyse par éléments finis, le calcul statique et le module interface de CAO. Le système donne plus que 15 dessins pour une entrée de données d'environ l ou 2 pages, en plus d'impressions graphiques et de listes de sorties de données.

**ZUSAMMENFASSUNG**
Vorliegendes Dokument präsentiert ein CAD System für den integrierten Brückenentwurf. Das System besteht aus mehreren Modulen, wie z. B. dem Modul für die statische Berechnung mit Hilfe der Finiten Element Methode, dem Modul für die Bewehrungsberechnung und dem CAD Interface Modul. Die Eingabe besteht aus nur ein bis zwei A4-Seiten. Mit diesen Eingabedaten produziert das System vollautomatisch mehr als 15 Konstruktionszeichnungen, Uebersichtspläne sowie eine geschlossene statische Berechnung in Listenform und in graphischer Form.

## 1. INTRODUCTION

Computer codes for structural analyses, e.g. finite element programs, have been in use for some decades, while CAD has emerged during the last ten years. It is widely recognized that improved efficiency would be achieved if computer aided structural analysis, design and drafting were to be integrated. This is the concept of CAE, computer aided engineering.

In spite of this recognition and focus on CAE, however, there is a lack of CAE systems except for research purposes. One great exception is VV541, a system developed for the design of skew frame bridges. This system has been developed by NordCad AB on behalf of the Swedish Road Administration.

## 2. OUTLINE OF VV541

Skew frame bridges are one of the most common bridge types in Sweden, with a production of approximately 100 annually. They are used for spans up to 25 m and are made of reinforced concrete.

Owing to its skewness, a skew frame bridge demands comprehensive calculations. This is one reason for development of VV541. Another reason is that variations in shape are limited by virtue of the structure being a bridge. For an input of approximately 1-2 A4 pages of data, the system will produce more than 15 working drawings apart from graphical print-outs and lists of output data. The drawings are automatically transferred to GDS, a general purpose CAD system developed by McDonnell Douglas. After some minor adjustments, such as the moving of text blocks which are in conflict with other text blocks or lines, the drawings are plotted.

VV541 is implemented on Prime and VAX computers. The system, Fig. 1, is fully integrated and includes a number of separate modules. Each run can start or restart any module, subject to logical restrictions such that the reinforcement module cannot be executed unless the finite element analysis module has been executed.

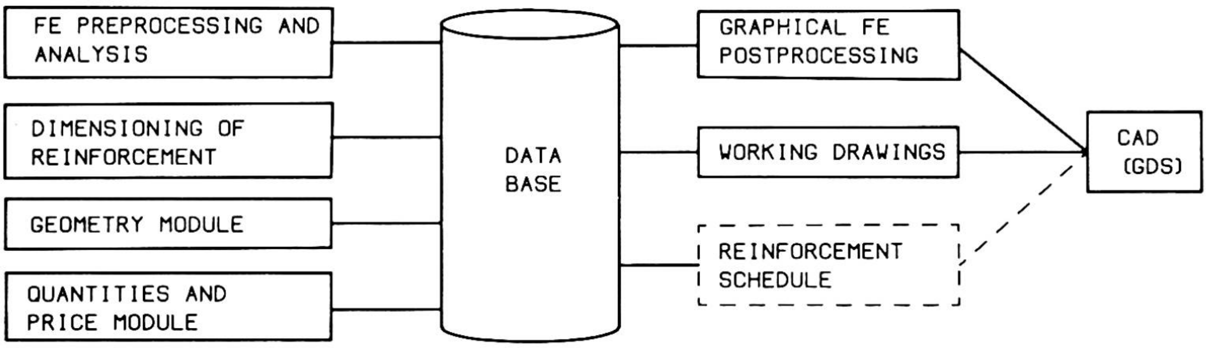


Fig. 1 The VV541 system

## 3. PROGRAM MODULES

### 3.1 Finite element preprocessing and analysis

A skew frame bridge is preferably analysed by the finite element method. The finite element system in VV541 includes shell elements and rigid links. The finite element coding is based on STRIP, a well known Swedish general purpose system.

The real benefit of this module lies in finite element preprocessing. In contrast to ordinary finite element systems, the user need not specify nodes and elements, but only the corner coordinates and dimensions of the slab, the abutment walls and the wing walls. This drastically reduces the time spent on the geometry conditions and, furthermore, the tedious calculations of nodal coordinates are performed by the preprocessor.

As regards the loading cases, the user need only specify the loads on the real system and not the loads on the elements which is the standard procedure. Furthermore, traffic loads are automatically generated in accordance with Swedish specifications. The traffic load is modelled as a uniformly distributed load and a group of 3 moving axle loads, with varying distances between the axles. All loading cases are automatically combined into a number of combinations. The total number of loading cases and combinations usually exceeds 50.

The results of the finite element analysis are presented in an output list, but only for the combinations to be used in the design process.

### 3.2 Graphical finite element postprocessing

It can be difficult to grasp immediately the thick piles of paper output from the analysis. Accordingly, in the postprocessing module there is an option for computer graphics. Any result of a load combination can be displayed graphically which, in turn, gives an inexperienced designer a unique opportunity to really understand the behaviour of a bridge under various loading conditions.

VV541 presents the graphical results either as iso curves, Fig. 2, or as vector graphs, Fig. 3. The abutment walls are tilted 90 degrees and are presented on the same picture as the slab. The result can be presented on paper or on a CAD screen. In the latter case the results can be presented in colour graphics with iso values ranging from dark blue to dark red.

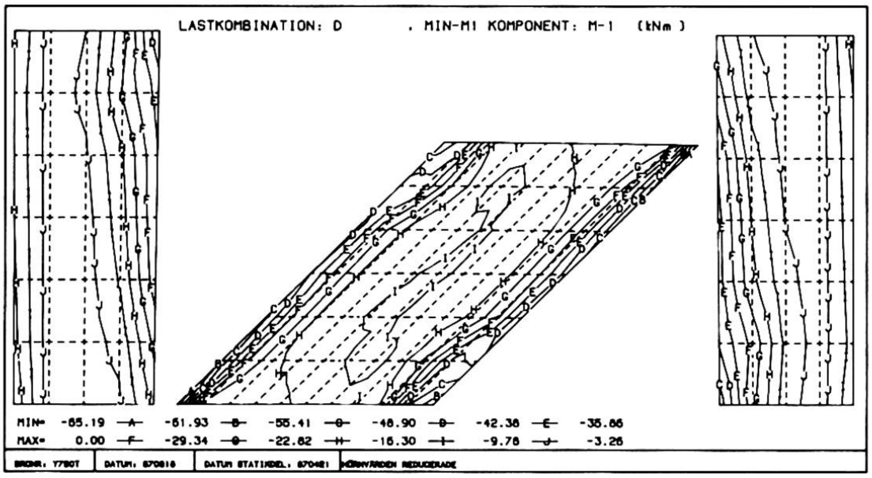


Fig. 2 Graphical postprocessing, iso curves

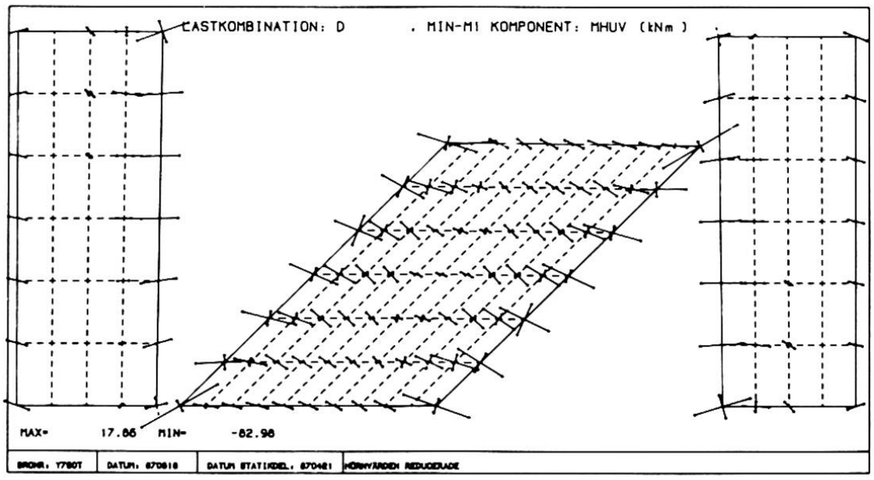


Fig. 3 Graphical postprocessing, vector graphs

## 3.3 Dimensioning of reinforcement

The reinforcement dimensions are determined on the basis of the static analysis, complemented by input data regarding the choice of concrete and reinforcement grades.

The structure is divided into a number of regions which are evaluated, including calculation of stresses and curtailment of the reinforcement. One example is the region in the principal direction of the top reinforcement on the left hand side of the slab.

Compared with the design of other structures, bridge design is somewhat more complicated. For instance, the layers of reinforcement in the slab will generally not be at right angles to one another. Special attention must be given to reinforcement in several layers and to an option of placing the principal slab reinforcement in a fan shape.

The results can be presented in various ways according to the options selected by the user. The calculated reinforcement is kept in the data base for further use in the production of the working drawings.

## 3.4 Geometry module

In order that the drawings may be produced, the input data must include the choice of edge beam, camber and so forth besides the coordinates and dimensions. However, the major information already exists in the data base in the form of general values for primitives such as points, lines, figures and reinforcement. These values must be changed into calculated values for the actual bridge structure.

A special program in the VV541 system generates these general values, but this program lies outside the control of the end user. The values are copied into the data base at the time of the first execution. This information amounts to approximately 11000 lines of text.

The geometry module preprocesses the drawings and will also present tables for setting out coordinates.

### 3.5 Quantities and price module

Based on the module for dimensioning of reinforcement and the geometry module VV541 calculates quantities and total estimated cost for the structure. The output is separated under headings as reinforcement, concrete, form face, ...

One advantage of this module is the possibility of getting a fast and accurate cost estimation of a redesign.

### 3.6 Working drawings and CAD

VV541 composes drawings out of figures in the data base. These drawings are automatically transferred into the CAD system GDS. This transfer is performed at a high level, which means that not only lines and text blocks are transferred but also a hierachical system consisting of objects. For instance, the command "query object" in GDS and the "hitting" of a reinforcement bar gives the answer: AWLT:REINFORC:EX133 which means reinforcing bar EX133 on figure AWLT (Abutment wall left side).

Furthermore, the Swedish Road Administration have made some special menus for VV541 within GDS. The purpose of these menus is to enable a user with no special knowledge of GDS to adjust the drawings. The adjustments should preferably be made on a colour screen, since VV541 makes use of the colour graphics option in GDS.

The drawings can be divided into reinforcement, dimensioning and setting out drawings. Fig. 4 and 5 show two examples of non-adjusted drawings.

## 4. ACKNOWLEDGEMENTS AND CONCLUSIONS

Automation of the design process is a very complicated and difficult task. Consequently it is of greatest importance to ensure that the system does not assume command but becomes an indispensable tool for the designer. It is hoped that this is achieved in the case of VV541 by print-outs at every level and by enabling the designer to adjust and modify the final drawings.

Development of VV541 started in the late seventies. At that time, interactive CAD-systems were almost unknown, which means that the development team has continuously had to adapt the system to the latest computer technology. As a matter of fact, the real breakthrough of VV541 did not occur until it was properly interfaced with CAD. This updating process can obviously be quite expensive, but fortunately this has been limited by the well designed systematization and modularization of VV541.

The coding has been quite complex, even though only skew frame bridges can be analysed. It is quite astonishing how much a "standard" structure can vary.

Finally, it can be stated that in VV541 a designer has a tool which facilitates the design process and a system which can easily evaluate the effects of an eventual redesign.

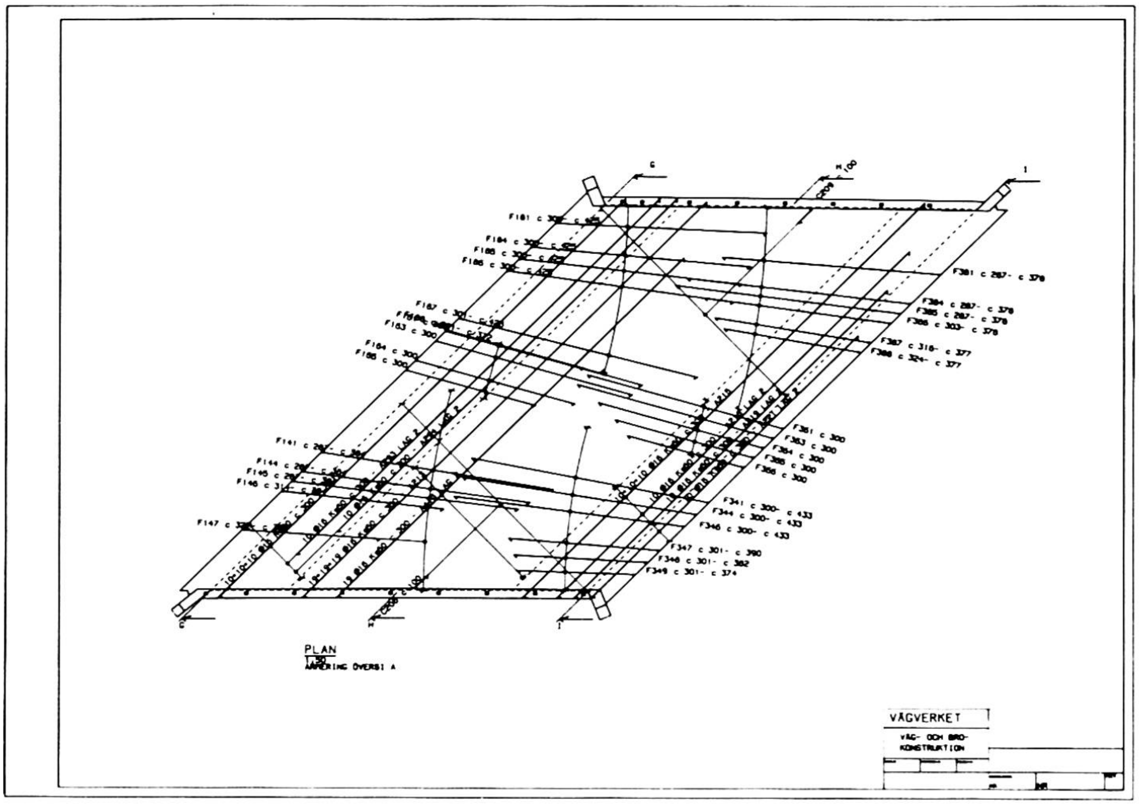


Fig. 4 Reinforcement drawing

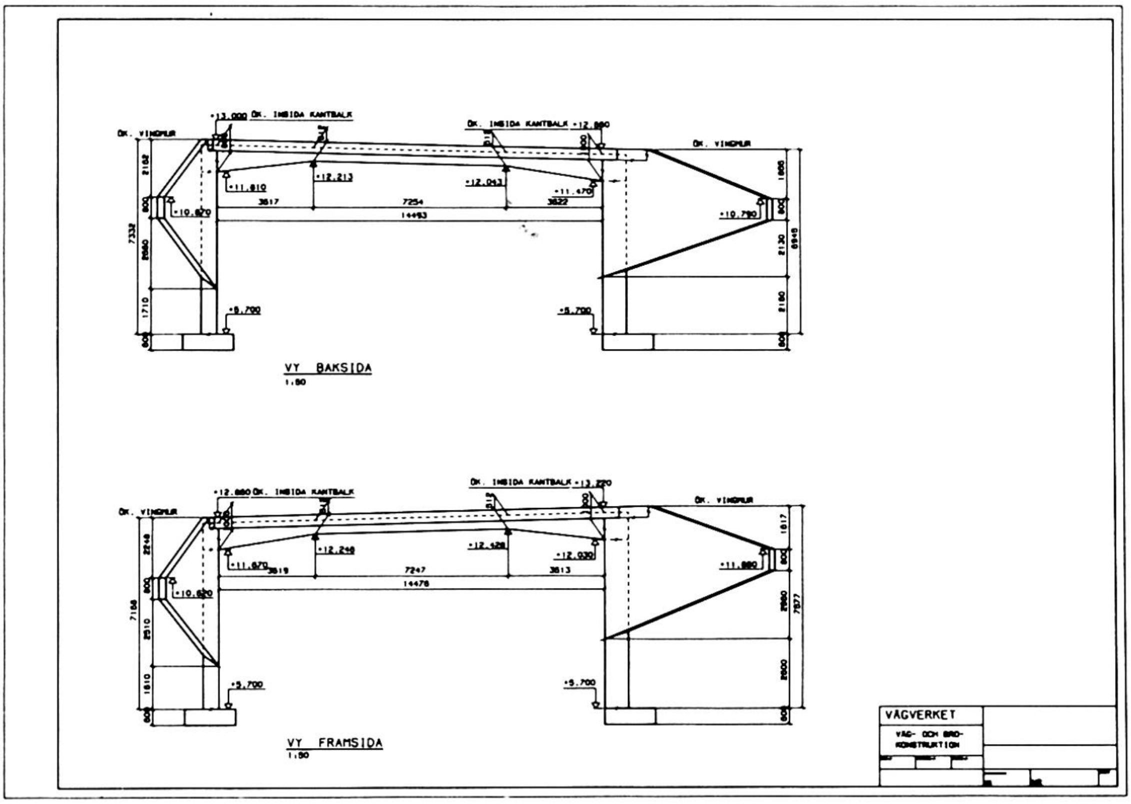


Fig. 5 Dimensioning drawing