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Autor: Schürmann, Christof H. / Weber, Burkhard

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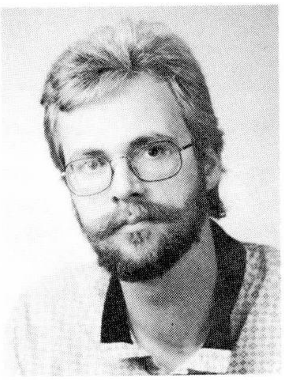
Integrated Expert System for the Design of Steel Structures

Système expert intégré pour l'analyse des constructions en acier

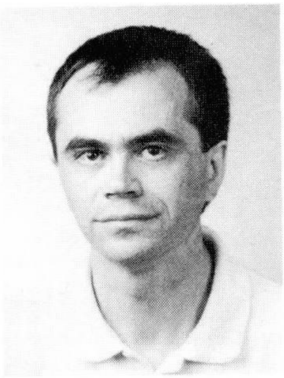
Ein integriertes Expertensystem für normgerechte Nachweise im Stahlbau

Christof H. SCHÜRMANN
Dipl.-Ing.
Ruhr-University
Bochum, Fed. Rep. of Germany



C.H. Schürmann, born 1960, received his degree in civil engineering at the Ruhr-University of Bochum, FRG, in 1986. Since then he has been active in research on integrated, microcomputer-based design strategies in structural engineering on microcomputers. His special research field are knowledge-based approaches of design strategies.

Burkhard WEBER,
Priv.-Doz. Dr.-Ing.
Ruhr-University
Bochum, Fed. Rep. of Germany



Burkhard Weber, born 1950, received his degree in civil engineering in 1974 at the Ruhr-University of Bochum. He obtained his Ph.D. in 1980 and his «venia legendi» in 1988 at the same university. Since 1981 he is head of a research group on software engineering. His main research interests are integrated software systems in CAE and CAD, using database techniques.

SUMMARY
The automation of structural analysis is accompanied by the development of up-to-date checking procedures and new ways of design. The rapid evolution of microcomputer technology has made decentral automation solutions for design tasks possible. This paper deals with a number of strategies for utilizing expert system techniques in the context of checking for accordance with code regulations for steel structures. Integrating this new technique in the existing software environment is achieved through the use of relational databases as global information support systems.

RESUME
L'automation des calculs statiques n'est plus un processus isolé; elle est suivie des concepts nouveaux de projet et de contrôle des constructions. C'est l'avancement rapide de la technologie qui a rendu possible cette automation decentralisée du processus de construction. Cette contribution présénte des stratégies pour l'utilisation des systèmes experts dans l'analyse des constructions en acier. L'intégration de cette nouvelle technologie dans l'environ de la programmation traditionnelle est rendue possible grâce aux banques des données relationales utilisées comme support de l'information.

ZUSAMMENFASSUNG
Die Automatisierung der Baustatik erfolgt nicht mehr isoliert, sondern im Verbund mit technischen Nachweiskonzepten und Konstruktionsprozessen. Die dezentrale Automatisierung des Entwurfsprozesses wird ermöglicht durch die rasante Entwicklung in der Mikrocomputerelektronik. Der vorliegende Beitrag erläutert einige Strategien zur Nutzung von Expertensystemtechniken im Bereich von Bemessungsnachweisen am Beispiel des Stahlbaus. Die Integration dieser neuen Technik in die vorhandene Softwareumgebung gelingt durch relationale Datenbanken, die als globale Informationsträger eingesetzt werden.

1. INTRODUCTION

In static analysis, strategies of automation have experienced a qualitative change due to the rapid evolution in microcomputers. The means of man/machine communication have also undergone significant changes in the course of the decentralisation of design work on microcomputers. This automation process for conducting integrated structural analysis is utilizing the latest development in software technology and focuses attention on the data links between structural analysis, dimensioning and final design. Relational databases that permit storage and easy retrieval of construction data have become key components for the information transfer between single tasks.

An important goal of integrated design is the inclusion of expert system techniques, with whose help design rules from codes, engineering experience and other sources can be readily assembled and put to use.

In this paper, first the implementation of design and checking procedures are discussed. Strategies of an expert system for checking steel buildings for accordance with the torsional-flexural buckling provisions of DIN 18800 are next dealt with. Different strategies for knowledge processing are shown and point out in which way such an expert system can effectively help the engineer carry out checking tests. The implementation of knowledge-based techniques in the existing software environment is carried out with a relational database, which communicates with the expert system via an "intelligent interface".

2. INTEGRATION OF CHECKING AND DESIGN

The integration of analysis, pre-dimensioning, design and checking is an active research field in structural informatics. Therein, the single tasks must be assembled to form a productive unit. For such an integration the modularisation of the software model and an open data transfer between the single software components with the aid of global, relational database concepts are necessary.

Through modularity the design process is split into a series of software components dealing with data input, static and dynamic analysis, dimensioning and CAD-based data output. Each software component deals with a single step of the whole design process. As an example for such a modular concept the microcomputer based program system SSt-micro (Fig. 1) [6], which permits integrated design of steel and R/C structures consisting of beam elements is presented. Static analysis therein, by plane as well as by 3D beam elements, can be done according to 1st an 2nd order theory and also based on limit state calculation. The different moduli offer the possibility to use the direct stiffness method in combination with the transfer matrix method to meet best the engineer's requirements in the refinement of results. Also moduli for dynamic analysis of structures are integrated in SSt-micro. The implemented design methods follow the German design codes DIN 18800 (steel) and DIN 1045 (concrete structures). For visualizing the data of every design step a multi-coloured grafical output is easy of access. .

The moduli are implemented in different programming languages, e.g. FORTRAN, C, LISP and PROLOG. In consequence this causes a heterogenous program- and data structure. For an integrated design work the different moduli can be combined by means of a global database, which defines all properties of a structure. The definiton is based on the different levels of design as for instance the data of static analysis, dimensioning and construction. It is open for equal data access of each modul.

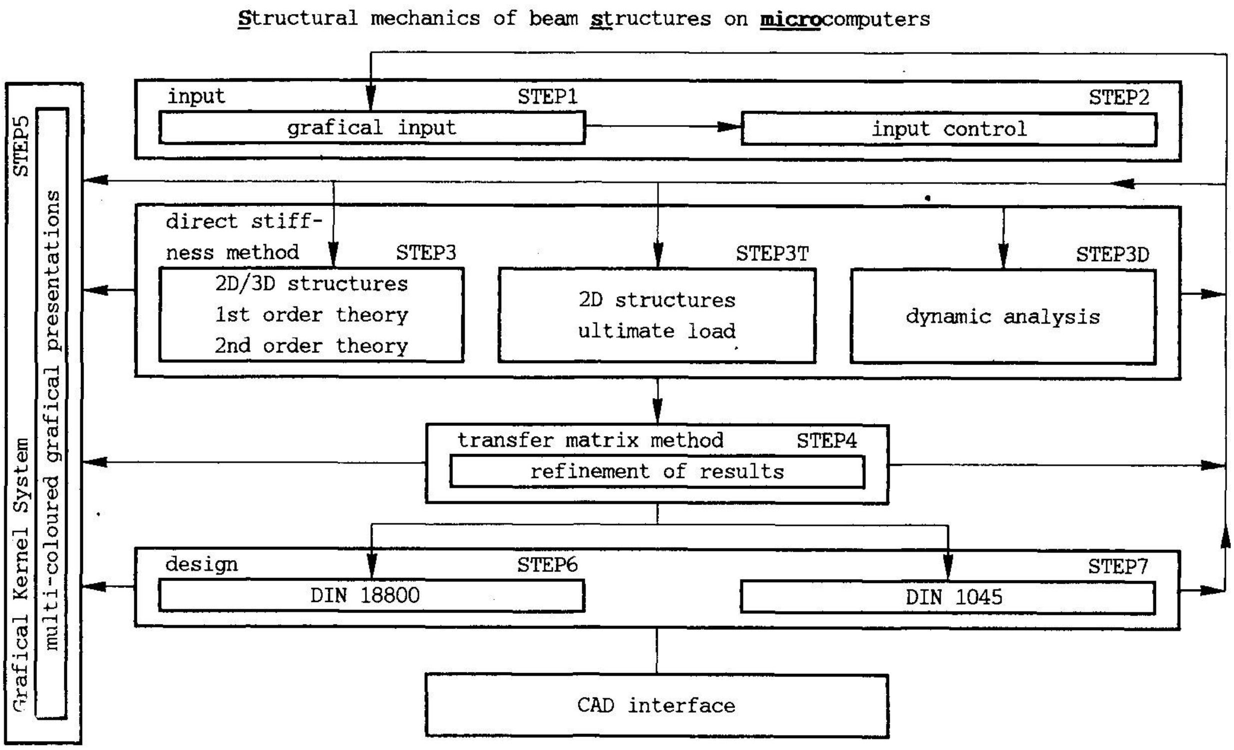


Fig 1: Modular structure of the program system SSt-micro [6]

3. KNOWLEDGE-BASED STRATEGIES FOR APPLICATION IN DESIGN OF STRUCTURES ACCORDING TO DIN 18800

Expert systems (XPS) are at the beginning of their development in the field of engineering. Some experience was available from other research fields, e.g. medical diagnosis or chemical analysis. But there are still many unanswered questions for the development and application of XPS in civil engineering problems. As a consequence of the rapid evolution in microelectronics also many powerful programming tools can be used to support the research on knowledge-based systems.

The main feature of XPS is the separation of knowledge representation and problem solving. Thus the knowledge becomes explicit for transparent representation and easy modification. The high interactivity of XPS supports the man/machine communication. The problem solving implemented on the level of meta knowledge grants an universal formulation of special engineering oriented problem solving strategies. However, the development of XPS for a special field supposes the assignment of multiple adequate knowledge representation and inference strategies. According to the German DIN 18800 some of these problems are examined.

To avoid torsional-flexural buckling the German design code DIN 18800, part two provides design rules for use in practice. This buckling problem is examined on a beam that is extracted from the complete structure [5]. The design rules are reduced to the determination of the collapse loads of an extracted beam. The torsional-flexural buckling is influenced by several factors, e.g. imperfections, section type, type and position of load and so on. The original design rules are roughly as follows:

- It is not necessary to consider torsional-flexural buckling as long as rotations of the beam end sections are adequately restrained.
- Simplified check for tors.-flex. buckl.: In all other cases (beams with arbitrary but unmovable end supports, constant section and constant axial load) pragraph 306 can be applied.
- The saftety check must be conducted in accordance with formula (301).

The whole information defined in DIN 18800 and their mutual dependencies direct the proceeding for the application of the right set of design rules. The efficient and complete definition of all relevant information and the selection of the appropriate rules for a special safety check is a main problem in using technical codes. The several design rules include different types of knowledge that can be separated into: properties of structural elements, tables, numerical functions and logical relations. While the representation of numerical functions and tables in programs is well understood, we focus on the other points mentioned above. Furthermore, the usage of a design code, e.g. the DIN 18800 can be subdivided into following steps:

- selection of a beam for the safety check,
- determination of the relavant rules and properties,
- calculation of the necessary data (e.g. the internal forces),
- safety check in accordance with the selected design rules,
- in case of rule violations: modification of properties and new safety check.

By use of knowledge processing strategies a design code can be represented in a knowledge base. The inference mechanism simulates the decision process for the safety check of the beam. A natural way formulating design codes are production rules [1]. The conditions of these rules that are proved by the inference mechanism consist of logical assertations and the conclusions are actions that take place if the conditions are true. Some design rules of DIN 18800, part two, formulated as production rules are as follows:

check of safety is par_322_304 if load_comb of beam_forces is axial_load_only and rotation of beam is restrained.

check of safety is par_322_305 if load_comb of beam_forces is axial_load_only and simpl_check of beam is true and design_rule_301 of beam is ok.

rotation of beam is restrained if symmetry of beam_sec is two_ax_symmetric and shape of beam_sec is i_shape and design_rule_305 of beam_safety is ok.

In the case of DIN 18800 and also for other codes, the goal-driven backward chaining strategy can be used to get a solution of the dimensioning problem. This strategy permits to hypothesize a potential solution, e.g.: 'The safety check of beam no. X is ok.', which subsequently can be proved or disproved. During this process all relevant rules defined in the knowledge base are automatically evaluated.

For the implementation of object-oriented knowledge processing strategies the conditions and conclusions of the rules are structured as object-attribute-value triples (O-A-V triples) to represent not only the logical relations of a special field, but also the structure of the underlying objects. The advantage of using O-A-V triples is the possibility to summarize different triples in a frame (Fig. 2) that defines a class of objects and consists of slots that hold the associated information belonging to the objects. The slots in a frame of an object can represent the possible values of the attributes or defines links to subobjects represented by other frames. Interlinking frames build a taxonomy that explicitly define the mutual dependencies of the objects of a special knowledge field. The inference strategies used in a taxonomy are manifold and are not as strictly defined as the rule-oriented inference strategies. In a taxonomy one can use inheritance strategies, procedural attachments or define default-values [2]. Fig. 2 shows frames defining some objects of a beam structure using inheritance strategies to share common data.

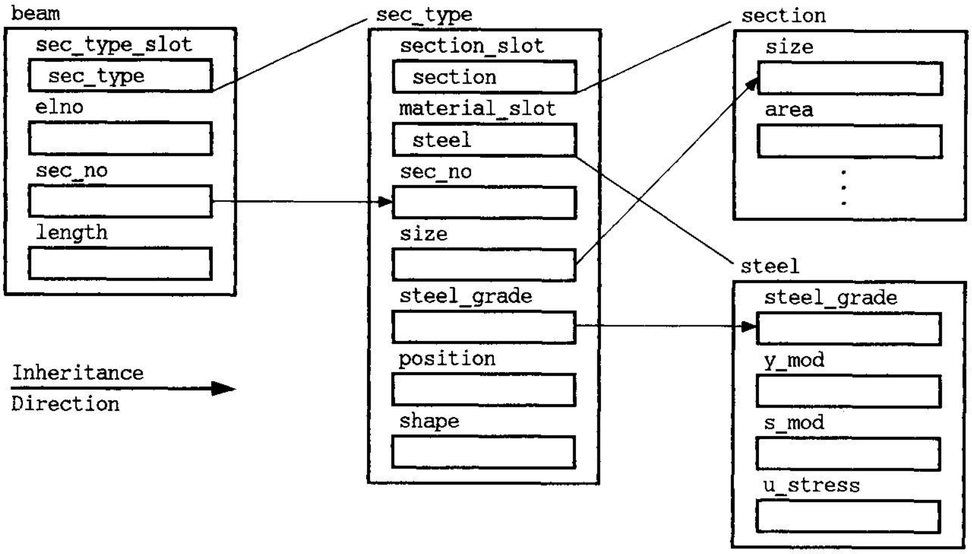


Fig 2: Object-oriented representation of structures by frames (partial view)

By the combination rule-oriented and object-oriented knowledge processing strategies the syntactical as well as the semantical aspects of knowledge can be represented which leads to the development of hybrid expert systems.

The developed expert system prototype introduced in the following chapters is implemented in PROLOG. Designing the expert system we integrated special software components delivered with the PROLOG-system for defining a rule base and a taxonomy in a pre-defined meta language [4]. The numerical procedures are implemented by interfaces to FORTRAN and C.

4. APPLICATION OF AN EXPERT SYSTEM FOR CODE-CHECKING

The following example illustrates the consultation of an expert system for the above mentioned DIN 18800. The example deals with the checking of a beam element of a frame structure. In the interactive dialog the user has to give information on the special problem while the inference process is carried out by the system. By selecting the how- or why-option the system can explain the used concepts or the drawn conclusions:

1) Enter steel grade of section ?

    1) st37
    2) st52
    3) unknown
    4) how
    5) why

Choice: 1

2) Enter shape of section ? heb500
3) Enter value for radius of gyration izg [cm] of section : how

```
Comment on design rule (308):
To simplify matters it is allowed to compute with the radius of gyration
iz instead of izg (radius of gyration of flange).
Hit any key to continue...
```

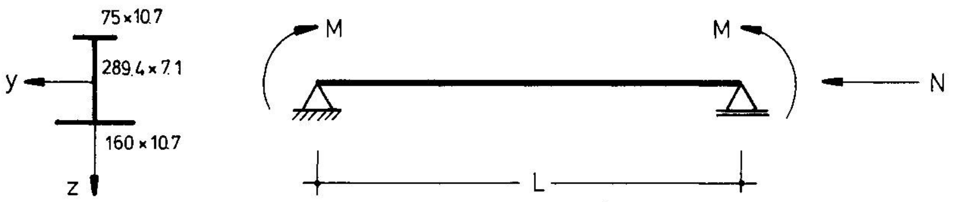
```
3) Enter value for radius of gyration izg [cm] of section : 7.84
4) Enter type of stiffening :
          1) brickwork
          2) trapezoidal_plate
          3) contin_rot_spring_supp
          4) point_supp
          5) none
          6) unknown
          7) how
          8) why

Choice : 4
          .
          .
7) Enter value of bending moment My [kNm] ? 465.84
          .
          .
The determined paragraph to avoid torsional-flexural buckling is:
          1) par_333_310_e
(e)xplain ,(c)ontinue <c> : e
```

```
[ How was check of safety = par_333_310_e determined ? ]

Since [1]  load_comb of forces = simple_bend
and   [2]  type of stiffening = point_supp
and   [3]  axial_force of forces = none
and   [4]  status_307 of design_rule_307 = not_ok
and   [5]  sym_of_web of section = yes
and   [6]  status_309 of design_rule_309 = ok
then check of safety = par_333_310_e
```

```
[ How was status_307 of design_rule_307 = not_ok determined ? ]

Since [1]  slen_rat_zg of beam = 0.6777625
and   [2]  max_value_307 of design_rule_307 = 0.5
and        0.6777625 > 0.5
then status_307 of design_rule_307 = not_ok
```

An important demand for the design of knowledge-based systems is their ability to estimate the inferred conclusions. Many complex design problems demand the use of adoptions and simplifications, which in further steps are improved to get the final results. This strategy of "iterative design processing" is a basic solution strategy in structural design.

In the case of DIN 18800 it is possible to extend the expert system to automatical search for the valid properties of a beam. All relevant rules to avoid torsional-flexural buckling are activated to check the ultimate plastic stress of the decisive section. To ensure the monotony of the used inference strategy it is necessary to eliminate all inferred conclusions in the dynamic database before execution of the next iteration step. Through the implementation of



1. design example

L = 2.50 m , max N = ?
system answer: N = 550.0 kN

2. design example

N = 550 kN , max L = ?
system answer: L = 1.61 m

3. design example

N = 200 kN , l = 2.50 m , max M_y = ?
system answer: M_y = 29.79 kN

St 37, welded section

A = 44.62 cm^2
Z_M = 8.65 cm
I_y = 6172.74 cm^4
I_z = 338.55 cm^4
I_T = 12.64 cm^4
i_z = 2.754 cm
i_p = 12.08 cm
I_ω = 28004.7 cm^6
M_{ply} = 113.84 kNm

Fig. 3: Beam for knowledge-based analysis in accordance with DIN 18800

these iteration procedures it is possible to simulate the dimensioning process of the design examples shown in Fig. 3 by the expert system. The initial information for the iteration is incorporated into the system through a interactive dialog with the system.

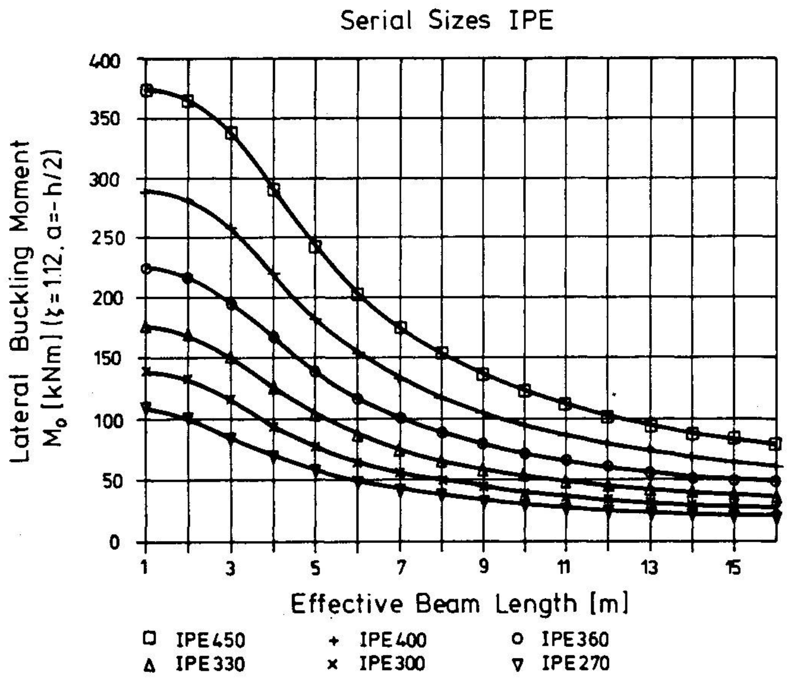


Fig. 4: Automatic generated design diagram in accordance with DIN 18800

Another utilization involving iterative processes applied to knowledge bases is the automatic generation of user defined design diagrams for special structural elements. Discrete properties of structural elements are varied automatically. The ultimate load of a beam, e.g. is determined in accordance with the code rules defined in the knowledge base. By the use of a grafical interface the resulting curves can be displayed or plotted as for instance shown in Fig. 4 for the diagram that shows design curves for the lateral buckling moment of an I-shaped beam.

5. COUPLING RELATIONAL AND OBJECT-ORIENTED DATA STRUCTURES

The duality between relational and object-oriented data structures (Fig. 5) makes it feasible to integrate knowledge-based techniques by use of a global, relational database (RDB). RDB's presently show their conductivity in the field of structural design [3]. Relational data structures transformed in 3rd normalform represent object classes equivalent to objects defined in a taxonomy. The mutual dependencies of different objects involved in the design process are defined in the relational data model and are carried out by the use of primary and foreign key attributes. A more effective and explicit definition of object structures is possible through a taxonomy using inheritance strategies. The adoption of meta relations makes it possible to implement an intelligent object manager that is under control of the expert system. The coupling between the relational data model and the taxonomy is carried out through the use of the inheritance of foreign keys from objects to subobjects of the taxonomy. The external database interface is automatically activated by way of procedural if-needed attachments when object data is needed in the inference process.

However, for an effective implementation of the model it is necessary to install a data buffer to avoid the activation of the database interface for each O-A-V triple. To minimize the external data access to the relational database the object manager only activates the interface to transfer the data of a whole object that is uniquely defined by its key attributes residing in the meta relation.

The relational data query is implemented in a special interface to the above mentioned SSt-micro system, based on SQL. With this special implementation we have the possibilty to make a fast, automatically managed, indexsequential data access to the SSt-micro database. With this model all information produced by other software components for instance the internal forces, section properties, material data, system geometry and so on, can be incorporated interactively into the expert system without any user-intervention. As a result the system dialog can now focus on the relevant information dealing with the code regulations. In future the model shall be expanded for use in a blackboard model to integrate different expert systems dealing each with separate problems of structural design.

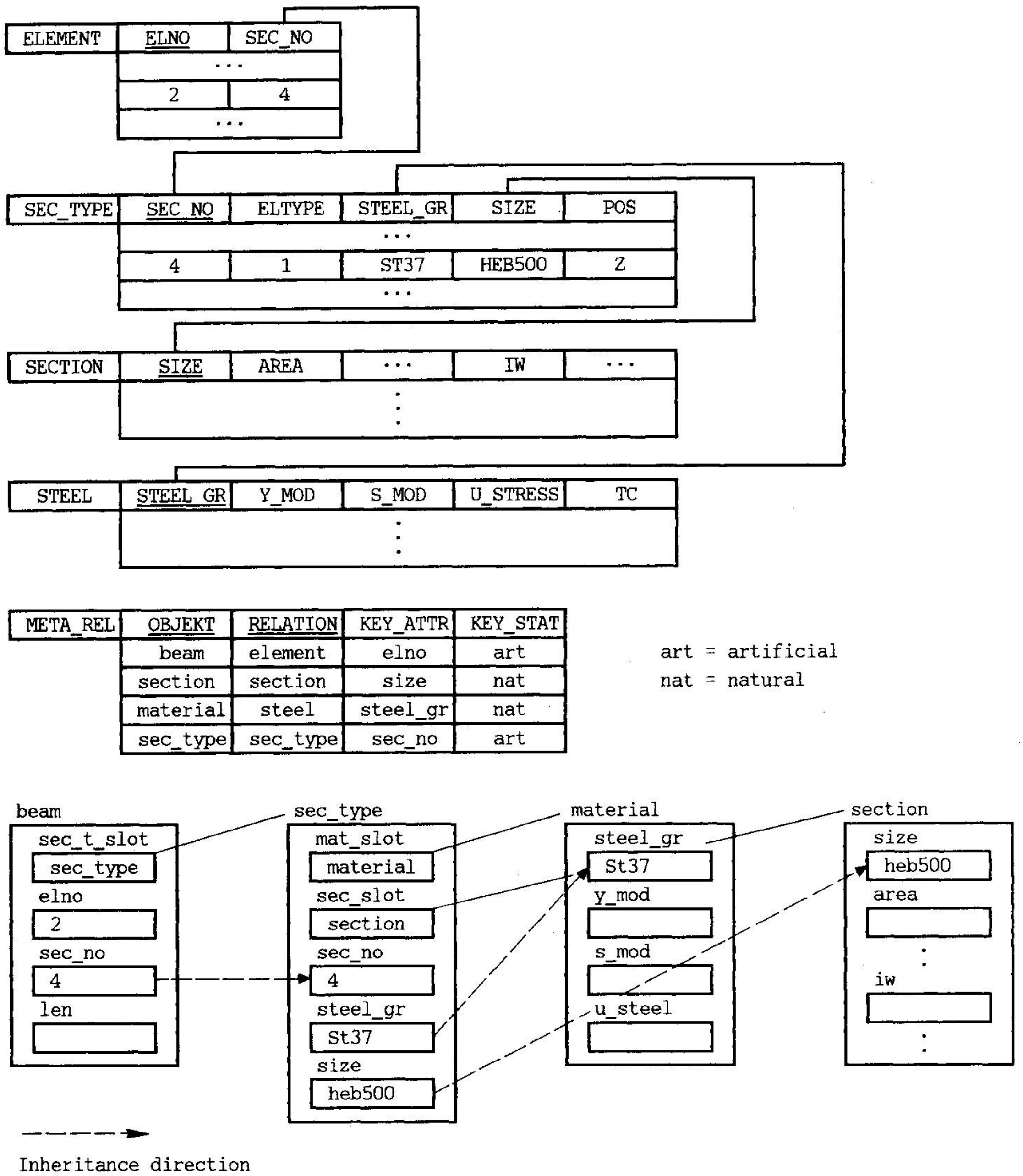


Fig 5: Duality of relational and object-oriented data structures

6. CONCLUSIONS

Codes and regulations which are a basic framework for the structural design process can be mapped and operationalized with the help of knowledge-based expert system techniques. In this way the non-numerical engineering decision process is simulated in the computer.

It has been shown that engineering problems cannot be solved all embracingly with a single strategy of knowledge processing, but the use of a variety approach can lead to successful results. The designed prototype "dimensioning expert" has a hybrid architecture to cover all aspects of the code regulation knowledge using rule-oriented as well as object-oriented techniques.

Special inference strategies have been mentioned to solve dimensioning problems of the design process as for instance the iterative checking of the implemented rules of DIN 18800 to change the properties of structural elements in accordance with the building regulations or the automatic generation of design diagrams. This leads to the development of special purpose expert systems dealing with design problems that require special expertise. The developed prototype shows the flexibility of this approach and demonstrates the great position expert systems can fill in the field of building codes and regulations.

Considering the design problem as a whole the coupling of the existing software environment and the new technology is a necessity. To cope with this problem relational database technology is used by way of a global database to coordinate the single tasks of the design process. That has been shown by the developed model for coupling relational and object-oriented data structures.

The hardware requirements of expert systems can be realized by today's 32-bit microcomputers, but they overcharge the current standard configuration of microcomputers used on top of the engineers desk. However, in a few years the application of expert systems in structural design will be widespread. In consequence the way of dealing with the computer and the design process itself will undergo a qualitative change. The final result of this evolution must not replace the human engineer but instead he should be extensively supported by expert systems to get more opportunity for creative engineering performance.

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