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COLLOQUIUM on:
"INTERFACE BETWEEN COMPUTING AND DESIGN IN STRUCTURAL ENGINEERING"
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STATIK: A Computer Program for Everyday's Structural Engineering Applications

STATIK: Un programme d'ordinateurs pour les problèmes courants de génie des structures

STATIK: Ein Computerprogramm zur täglichen Anwendung im Bauingenieurwesen

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Summary
Within the context of some of the developments in the field of computer applications to structural engineering which took place in Switzerland in the last 15 years, the criteria followed for the design of a new general purpose computer program called STATIK are presented. A number of specific questions concerning man-machine interface problems are raised which may serve as a basis for further more general discussions.

Résumé
On discute les critères retenus pour le développement d'un nuveau programme d'analyse structurale appelé STATIK, en tenant compte des conditions particulières qu'on retrouve en Suisse dans le domaine de l'application des ordinateurs au génie civil. Un certain nombre de questions concernant la relation homme-machine peuvent servir de base à des discussions ultérieures.

Zusammenfassung
Es werden die Kriterien geschildert, die zur Entwicklung eines neuen Computerprogrammes namens STATIK geführt haben, unter Berücksichtigung der speziellen Bedingungen, die in der Schweiz auf dem Gebiet der Computeranwendungen im Bauingenieurwesen zu finden sind. Eine Reihe Fragen tauchen auf, die als Basis für allegemeinere Diskussionen dienen können.

1. INTRODUCTION

If one considers the way computer programs for structural engineering applications are written and used the following classification seems reasonable:

a. Programs, generally written by non-professional programmers which are used only by their authors or by few very closed associates of their authors. Such programs are often found in the larger firms owning a computer. In fact, although this looks like a great duplication of efforts, it might well make sense to write programs for more or less personal use as the interface problems we are concerned with in this colloquium can then be easily solved in a local, personal way. As an example it is believed that most optimum design programs used today in structural engineering (and there are not many of them) are of this kind, design being too much influenced by personal taste and habits to be left to some not clearly understood black box program written for general use. But of course not everybody can write his own programs.

b. Programs written by professionsl programmers requiring from the user a high level of specific competence generally not found among practising engineers. Most well-known general purpose finite element programs are of this kind, an extreme example being NASTRAN which was written for use in the aerospace industry by highly professional numerical analysts. The use of such programs for civil engineering applications generally requires the professional services of a specialized software firm acting as an interface between the program and its user.

c. Programs written by professional programmers to be used directly by practising structural engineers for whom numerical analysis is only one, and seldom the most important, aspect of their professional activities.

The present paper is only concerned with this last kind of programs where interface problems between automatic computation and everyday's design work are of greatest concern. The criteria to be followed when developing such programs as well as the problems arising by their use are to be discussed. It is felt, however, that a discussion in very general terms would not make much sense. Too many factors greatly varying from place to place would have to be taken into account. Therefore, only some aspects of the developments which took place in Switzerland in the last 15 years and which are closely related to the activities of the writer shall be discussed. It is hoped that such a "case study Switzerland" will give rise to useful discussions and lead to generally valid conclusions.

The following factors certainly had a great influence on the historical developments of computer applications to structural engineering in Switzerland and indeed it would be interesting to compare and discuss the influence that similar factors had in different countries:

a. Swiss structural engineers are not too often confronted with problems where a sophisticated structural analysis would make much sense: Switzerland has practically no aerospace industry; unusual or unusually large structures are rare; rivers flowing near their sources are narrow and therefore not too difficult to span; since over 400 years no major earthquake has occurred; most large dams were designed and built before the advent of computers. However, there are some large reinforced concrete structures for nuclear power plants being designed today.

b. For many years Switzerland had by far the highest per capita cement comsumption of the world which is a good mesure of overall construction activities. Worth mentioning are the national and cantonal road construction programs with hundreds of individually designed, very slender and elegant cast-in-place reinforced concrete posttensioned bridges.

c. The vast majoritiy of Swiss civil engineers confronted with structural design works in relatively small, privately owned consulting offices. This is also a consequence of the Swiss political system as public works (including national highways) are generally managed by the cantons which tend to prefer local consulting firms.

d. Swiss building codes, at least compared with German, are rather liberal allowing considerable freedom in choosing design methods. No state employee checking each single computation exists as this is the case in Germany with the so-called "Prüfingenieure".

e. Switzerland is a rich country with one of the highest computer hardware density of the world. Access to computer facilities is therefore in general easy. As an example the Swiss Federal Institute of Technology in Zurich with some 7200 mostly undergraduate students has main computer facilities worth over 50'000'000 Sfr. not counting many small computers scattered about the institutes.

f. Four years of undergraduate studies are needed to become a civil engineer. At the Swiss Federal Institute of Technology in Zurich out of 12 mandatory and 4 non-mandatory semester courses on statics and structures only one non-mandatory course in the 7th semester deals with computer methods for structural analysis. Graduate studies leading to anything similar to a master's degree do not exist and only some 5

or 6 students reach each year the Ph. D. degree in civil engineering.

Within this framework a small group of research workers and Ph. D. students headed by the author of this paper has been active since 1962 at the Swiss Federal Institute of Technology in Zurich in the field of computer applications to structural engineering. One of our objectives has always been the development of computer programs to be used both for teaching purposes at our school and for practical applications by consulting structural engineers.

2. BACKGROUND HISTORY: THE PROGRAM STRESS

In early 1964 a magnetic tape with the source code of the program STRESS was sent to us from the Massachusetts Institute of Technology. After two years of efforts a modified version of the program was installed on the main computer of our school and a course for practising engineers was announced. We had, however, so many inscriptions that a second course in 1967 had to be held bringing the total attendance to nearly 600 engineers, a very large number for Switzerland. The programm STRESS has been used ever since for teaching purposes at both Federal Institutes of Technology in Zurich and Lausanne and found wide acceptance among Swiss consulting engineers. It certainly contributed very much to the spread and to the understanding of computer methods in structural engineering in Switzerland.

The main reason for this success is due to the fact that STRESS was the first finite element program specially designed for civil engineering applications with limited but clearly defined objectives: it can handle only linear elastic frames and trusses which is what most structural engineers not only need but also clearly understand; it does not attempt to design anything which, even today, would be a rather hopeless objective for a general purpose program; is is easy to use due to its simple problem-oriented input language which in many cases allows the preparation of new inputs just by extrapolation from old ones without having to study each time the user's manual, a big advantage specially for sporadic users.

The developments which took place at the MIT after STRESS are well known: the much publicized ICES project failed to attain many of the extremely ambitious and clearly utopian objectives that were set and was finally abandoned at the MIT. ICES, however, specially in Europe, had some offsprings like the "integrated" (whatever that means) systems GENESIS in England, ITS in Germany or SYSFAP in Belgium and it would be interesting to hear some comments on such programs from people directly involved in their development and use. The writer is rather skeptical toward such integrated systems, unless the word "integrated" is used in a restrictive sense meaning a series of programs for a specific application (like highway design) where the output of a program serves as input for its successor and not in

his original ICES sense meaning a number of programs for totally different applications (like survey, structural analysis and project management) all working on the same data base describing the object to be designed and built in very general, application independent terms.

3. STRESS'S SUCCESSOR: THE PROGRAM STATIK

After STRESS our group was involved in basic finite element research which led, of course, to many programs for personal use but also to two programs for general use: a program called PLATTE for linear elastic plate bending analysis where, for the first time, syntax diagrams for input description, as explained later, were used as well as extensive graphical output of results (e.g. contour lines of bending moments envelopes) and a program called FLASH for plate bending, plate stretching and shall analysis. The program FLASH is today regularly used for teaching purposes and has also become quite popular among Swiss consulting engineers being efficient and very easy to use. However, the points we want to make in this paper are probably best understood if we consider the criteria which led to the latest and largest of our programs: the program STATIK.

Although the STRESS program was a success, we were quite unhappy with it during many years: it was very inefficient (which many users never noticed as they never tried to analyse large structures); it has never been completely error-free mainly due to the unnecessarily complicated internal data organization making it extremely difficult to find programming errors; it could only handle prestressing in a very primitive way; it had no graphical output, no restart capabilities, etc. Finally, we decided to write a new state-of-the-art program to be used directly by Swiss consulting engineers assuming from them very much the same degree of competence as needed for STRESS and handling the same kind of everyday's relatively simple design problems. With a total effort of approximately 5 to 6 man-years the program STATIK was then developed according to the following criteria.

When using STATIK no difficulty should arise concerning the mathematical model used, i.e. only those problems are to be handled where an exact solution for a clear and well understood approximation of reality is possible. This requirement excludes all kind of nonlinear, dynamic and two-or threedimensional problems where the choice of the element mesh has an influence on results. STATIK can only handle linear elastic framed structures under statical loads as well as different kinds of cross section calculations. Much attention was paid to the load case prestressing. We also tried (and it is not yet clear if it is relly being used) to implement some simple design procedures for prestressed and non prestressed symmetric reinforced concrete cross sections.

Input preparation should be very easy also for relatively inexperienced sporadic users who are only supposed to read a very short user's manual (48 pages including examples and appendices) once. This is achieved by using so-called syntax diagrams for defining and describing in a very concise and clear way the problem-oriented, free format input language of the program. Figures 1 to 4 show some of these syntax diagrams. They are easily understood observing a few simple rules: the sequence of input data is found by following the arrows; a thick stroke corresponds to the beginning of an input statement, a triangle to its end; the first letter of the upper case words has to be punched on cards or typed on a terminal as it is; lower case words are identifiers referring to numerical or nonnumerical problem data to be specified; what is written between brackets can be left out, etc. The syntax diagram showing the overall structure of the program consisting of seven different modules ("QUERSCHNITT PROGRAMM" to "AUSGABE VON EINFLUSSLINIEN") is given in fig. 1. Fig. 2 shows the syntax diagram of one of these modules ("STRUKTURELLE EINGABE") used for specifying the structural input data of very general three-dimensional space frames with straight and curved members. Fig. 3 shows the syntax diagram of the program module "RESULTAT AUSGABE" used for requesting numerical and graphical output of results. A similar syntax diagram of the program FLASH for the input of structural data for very general continuous plane and space structures is given in Fig. 4. Syntax diagrams have proved to be an extremely useful tool not only for describing input languages (they are also becoming a standard tool for describing and defining programming languages, e.g. the syntax of the new ANSI-standard FORTRAN77 is defined by means of similar so-called railroad diagrams), but also because they immediately show what a program can do. Today, we consider them an indispensable feature of all programs written for general use.

Input echo and numerical output of the program STATIK appear on numbered pages of standard format (A4) with one or two headlines at each page which are generally used for the name and address of the consulting firm using the program. Printer control characters are not used as they are not understood by most terminals. Such details are mentionened here because they are very welcomed by practising engineers and also because they complicate programming considerably.

The Program STATIK has extensive graphical output capabilities. In all cases the drawing area is assumed to be 37 x 27 cm which corresponds to the screen size of the large storage tube Tektronix terminals. In fact, the STATIK program produces a graphic file which can be viewed directly on such terminals, a postprocessor being necessary to obtain the same drawing in any size on a plotter or on any other graphic device. Figures 5 to 8 show some of these drawings.

The program STATIK is written in FORTRAN for a large CDC Cyber Computer with a conversational remote job entry system (not a time-sharing system). It is specially designed to be used from remote terminals connected by telephone. This has the advantage of requiring only minimal fixed hardware investments from the user: a cheap alphanumeric terminal is all it is needed at least to start with. Later, a faster printer, a graphic terminal possibly with a hard-copy unit or a small plotter can be added to improve speed and user's comfort.

The program STATIK, if requested, automatically saves all problem data at the end of the last program module executed. The computations for a specific object can therefore take place in any number of subsequent jobs being possible to change problem data at any time and to execute program modules in any order. Some kind of interactive "computer aided design" is therefore possible. It should be noted, however, that interaction between the program and its user takes place at the level of subsequent, often very short jobs, and not at the level of each single line of input text as this is the case when using a time-sharing system. In fact, we think that for most structural engineering applications time-sharing would be an unnecessary luxury.

In October 1977, a course on the programs STATIK and FLASH with an attendance of approximately 250 civil engineers was held. It is too early to know if the success we had with STRESS can be repeated. Among our students, however, STATIK has been intensively used since nearly two years for all kinds of applications (sometimes without any specific theoretical background knowledge) becoming quite popular indeed.

Of course, as always when a program has been written, there are some features of STATIK we are not so happy about today. We also had some critics.

Some think that university employees should stick to research work instead of writing commercial programs like STATIK. Our answer is that the efforts leading to programs like STATIK are indeed to be considered research work, not in the field of structural analysis of course, but in the field of computer science. In fact, we did our best to solve the interface problem between the computer and its users just like conventional computer scientist do, for different problems and different users, when they develop, say, a new programming language. Our goals, however, are only attained when many peoples use our programs as an instrument for their professional activities which is only possible in a commercial environment.

It would be very much in line with our purposes to have STATIK run on relatively small computers as it could then be made available to many more users (e.g. a PDP 11/60 would certainly be powerful enough for most applications). We must admit, however, that we made a mistake experienced programmers should not make: in order to improve efficiency we introduced many

machine dependent features greatly impairing program portability. Although STATIK is completely written in FORTRAN it would certainly be an extremely long and tedious task to develop today a general, machine independent version of the program.

Graphical output was planned having in mind Tektronix storage tube terminals combined with hard-copy units as we thought such terminals will have a great future being relatively cheap and easy to connect to a large computer using asyncronous low-spead (300 to 1200 Baud) data transfer. Today, we are not so sure about this anymore. In fact, inexpensive small plotters working in the same way already exist and recent advances in microcomputer technology may soon make graphical refresh terminals with a high level of built-in intelligence easily available. However, the advent of new graphic terminals will not really impair the use of the program STATIK being a simple task to have the program produce a hardware independent instead of a Tektronix-oriented graphical file. Postprocessors are then used to produce graphical output on different hardware units (this solution was already implemented in one version of the program STATIK running in a large computing center in Zurich).

Quite contrary to many other programs who use English for input and output (e.g. STRESS), STATIK and FLASH use German. Rather provincial reasons led us to this choice as we really did not want our programs to be used from people living too far away from us, whose problems, habits and level of competence we do not understand too well. We were also somehow afraid of the maintenance problems arising when too many versions of the program are running in different places. Unfortunately, Switzerland is a multi-lingual country, and we already had to hear the complaints of our collegues at the Swiss Federal Institute of Technology in Lausanne who would be much happier with French versions of the programs.

4. FURTHER DEVELOPMENTS AND CONCLUSIONS

No further development of our programs FLASH and STATIK are planned as this would contrast with the objectives we pursued with them. However, we certainly want to pursue similar objectives in the future for different classes of problems and assuming from our users a different level of competence. Graduate studies leading to something else then a Ph. D. degree shall be introduced soon at our school which will also have a direct influence on our activities. In fact, we feel that there is ample room for computer scientists involved with practical computer applications to try to span the gap between the real needs of today's structural engineering and much of the sometimes brilliant but often isolated university research work.

General conclusions shall not be drawn here, the "case history" presented being rather intended to raise questions than to anwer them. However, as a kind of summary, some of these questions shall be given hereinafter.

Does a classification of programs distinguishing programs for more or less personal use, programs requiring specialists help and programs to be used directly clarify the situation ? How should a programmer take into account the way his program will be used ?

What is the influence of local conditions like those given for Switzerland on the development of computer applications to structural engineering in different countries ?

In which circumstances can integrated systems be useful ?

What can be done in order to make the use of a program, i.e. the preparation of input data and the interpretation of results, as easy as possible ? In which cases is this of primary importance ?

How can computer-aided design procedures be helpful in everyday's structural design work ? What kind of an interaction between the engineer responsible for the design and the computer is needed ? Can automatic optimum design programs be useful for structural engineering applications ?

What will be the influence of recent advances in computer technology like the proliferation of minicomputers to be used both off-line and in-line with a host computer ?

What should civil engineering students learn in order to be able to use such new instruments properly ?

It is hoped that such questions will help to clarify the interface problems we are concerned with in this colloquium and lead to useful and more general discussions.

Notice: The User's Manuals of the computerprograms STATIK and FLASH can be obtained from the Institut für Baustatik und Konstruktion, ETH-Hönggerberg, 8093 Zürich, Switzerland.

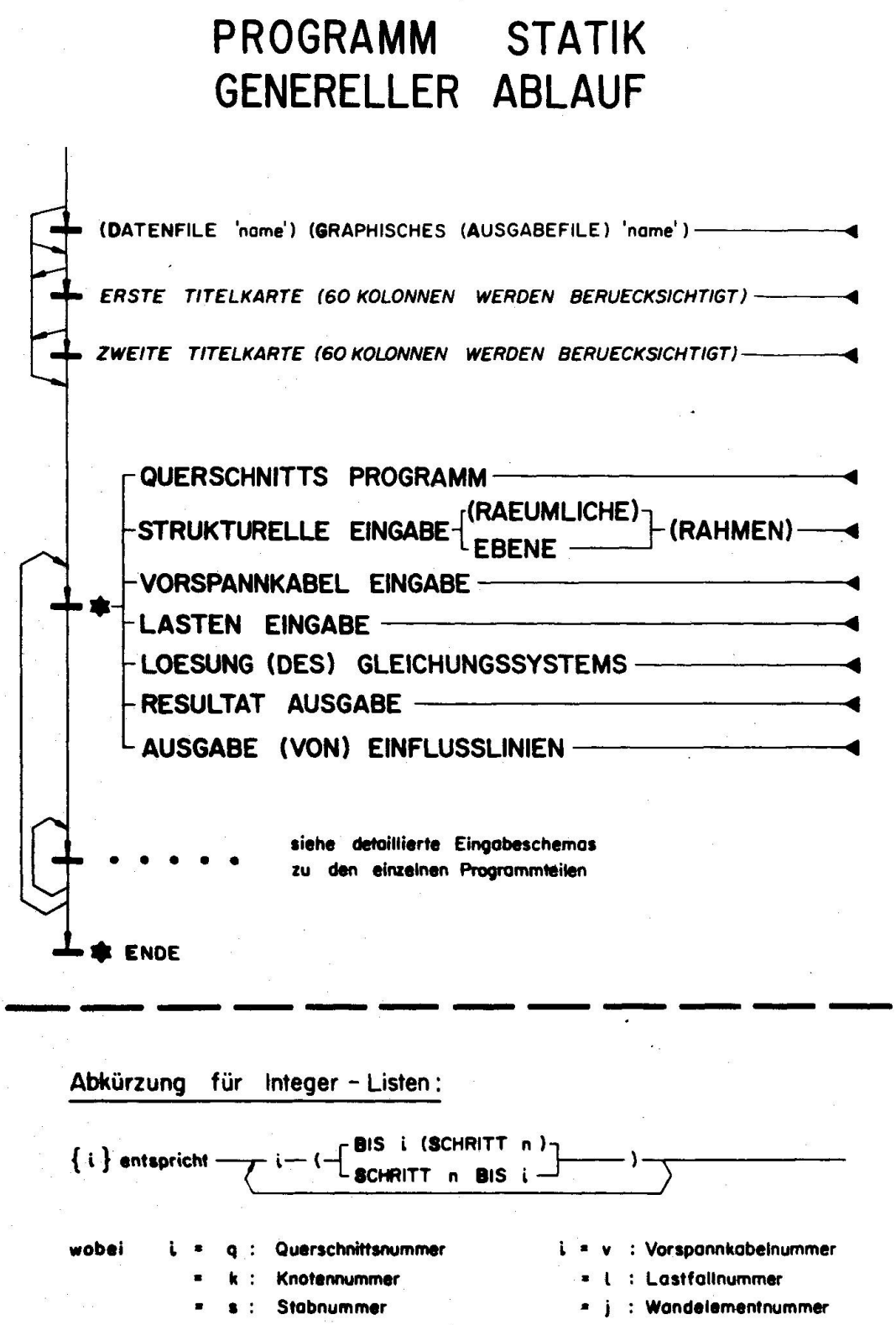

Fig. 1: Syntax diagram showing the overall structure of the program STATIK consisting of seven program modules callable in any order after specifying problem files and output headlines. The syntax of integer input lists used in subsequent diagrams is also shown.

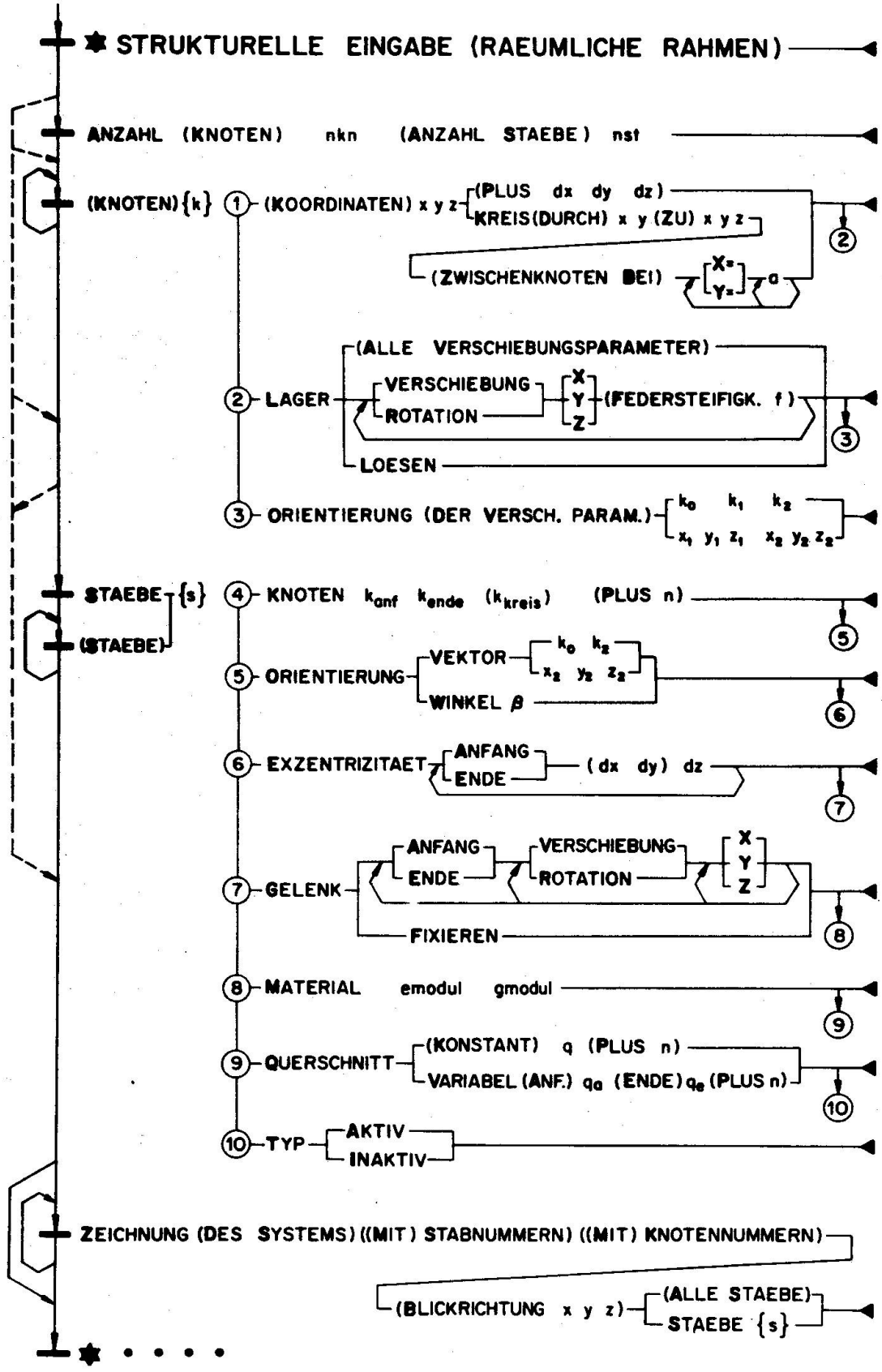

Fig. 2: Syntax diagram of the program STATIK for the input of structural data for space frames.

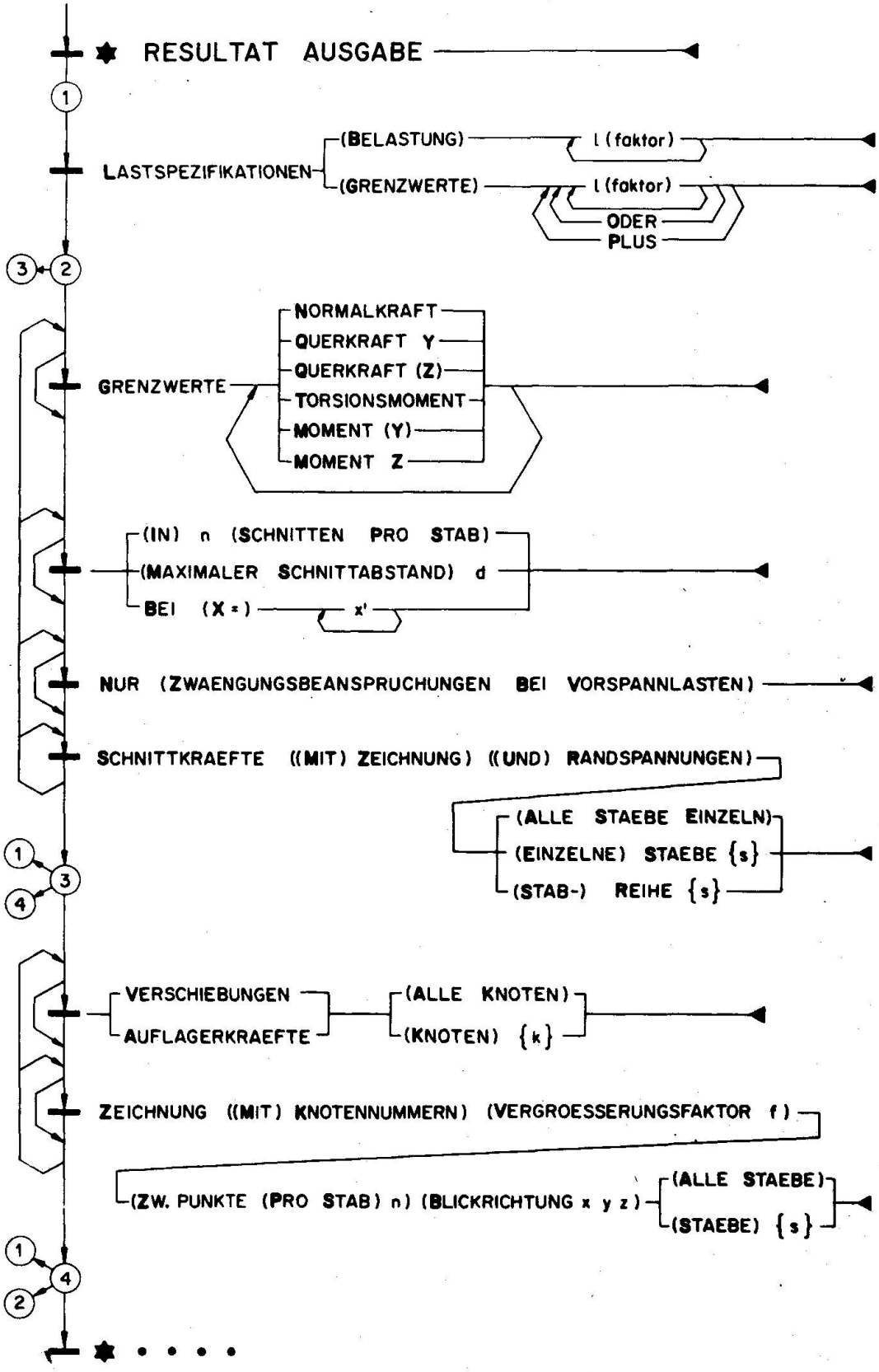

Fig. 3: Syntax diagram of the program STATIK for requesting numerical and graphical output of results.

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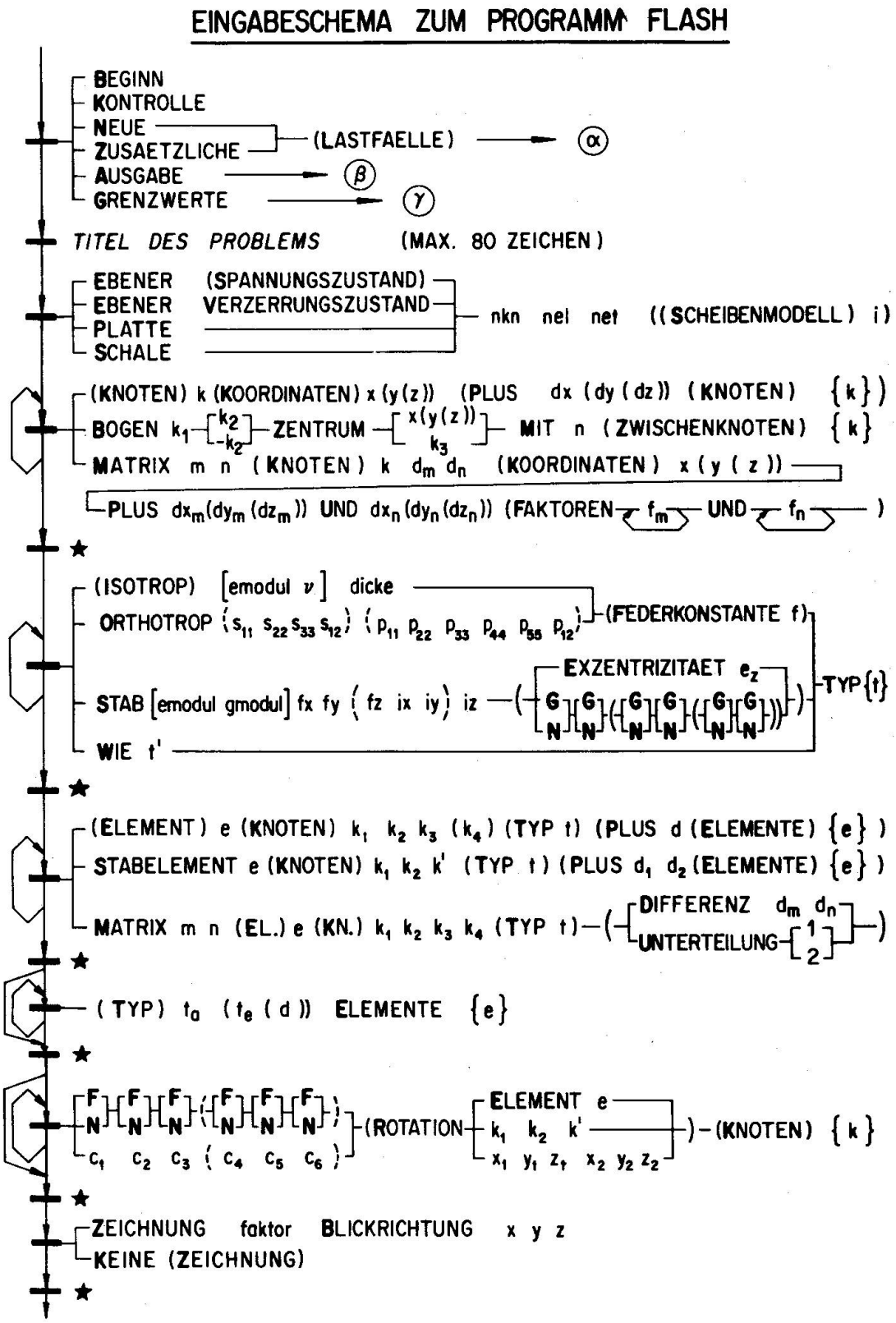

Fig. 4: Syntax diagram of the program FLASH for the input of structural data for plates and shells.

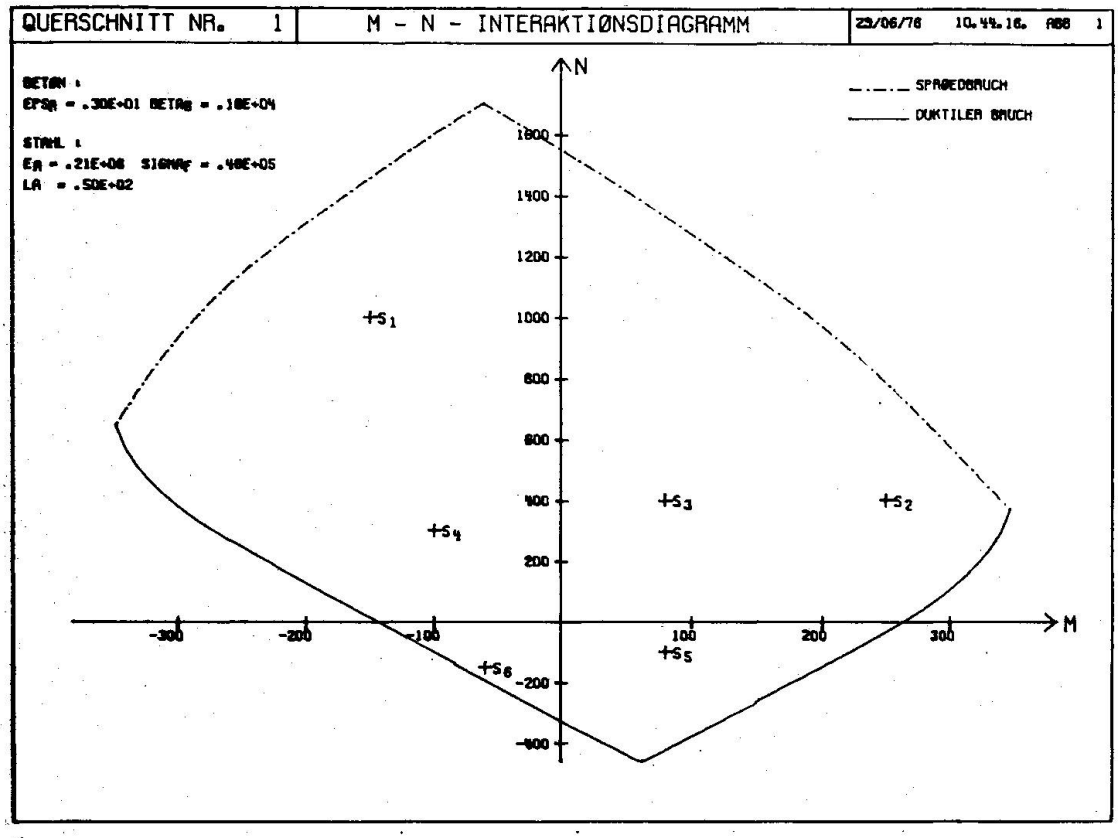

Fig. 5: Graphical output of normal-force bending-moment interaction for a reinforced concrete prestressed cross section.

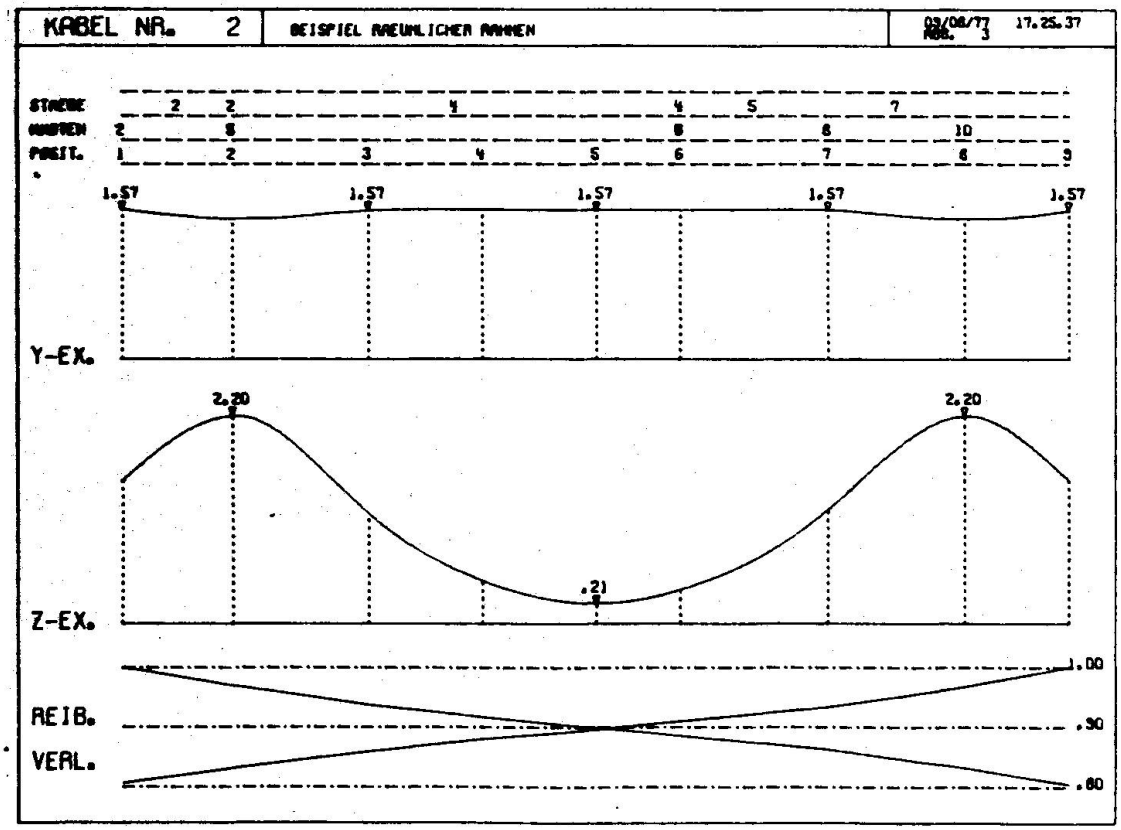

Fig. 6: Graphical output of prestressing cable geometry and friction losses.

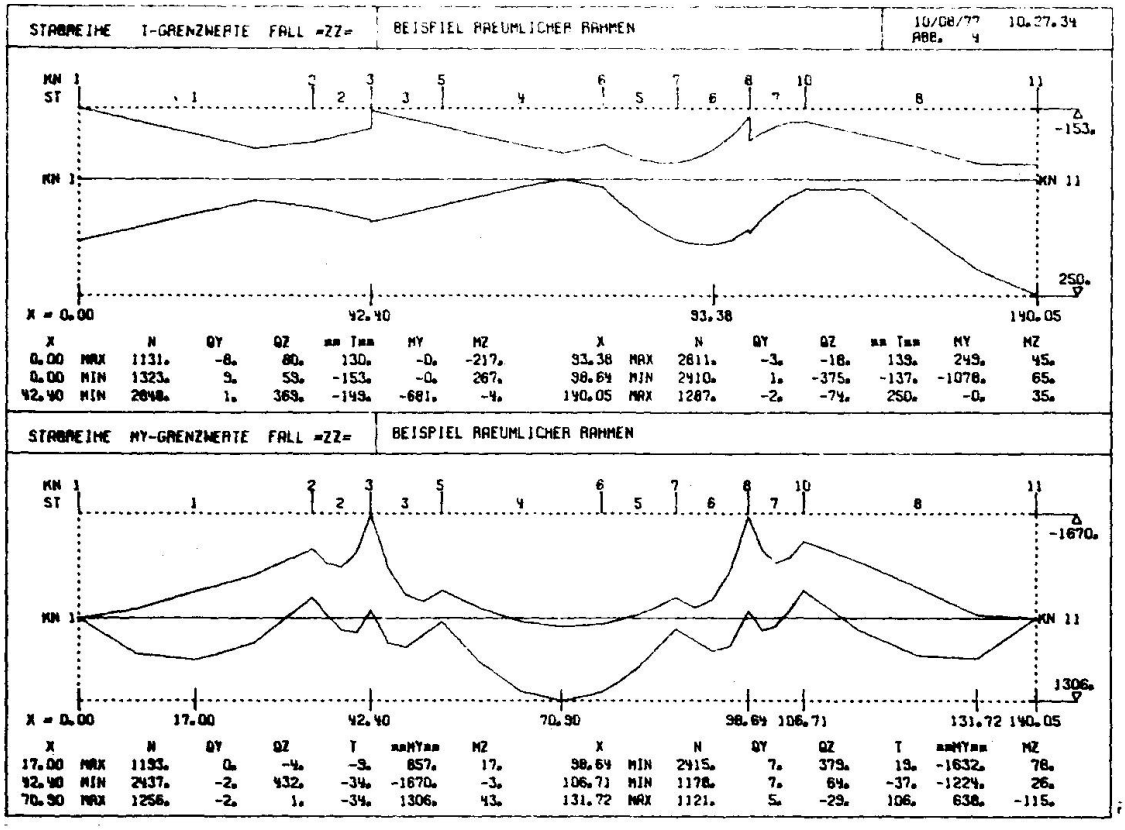

Fig. 7: Graphical output of torsional- und bending-moment envelopes.

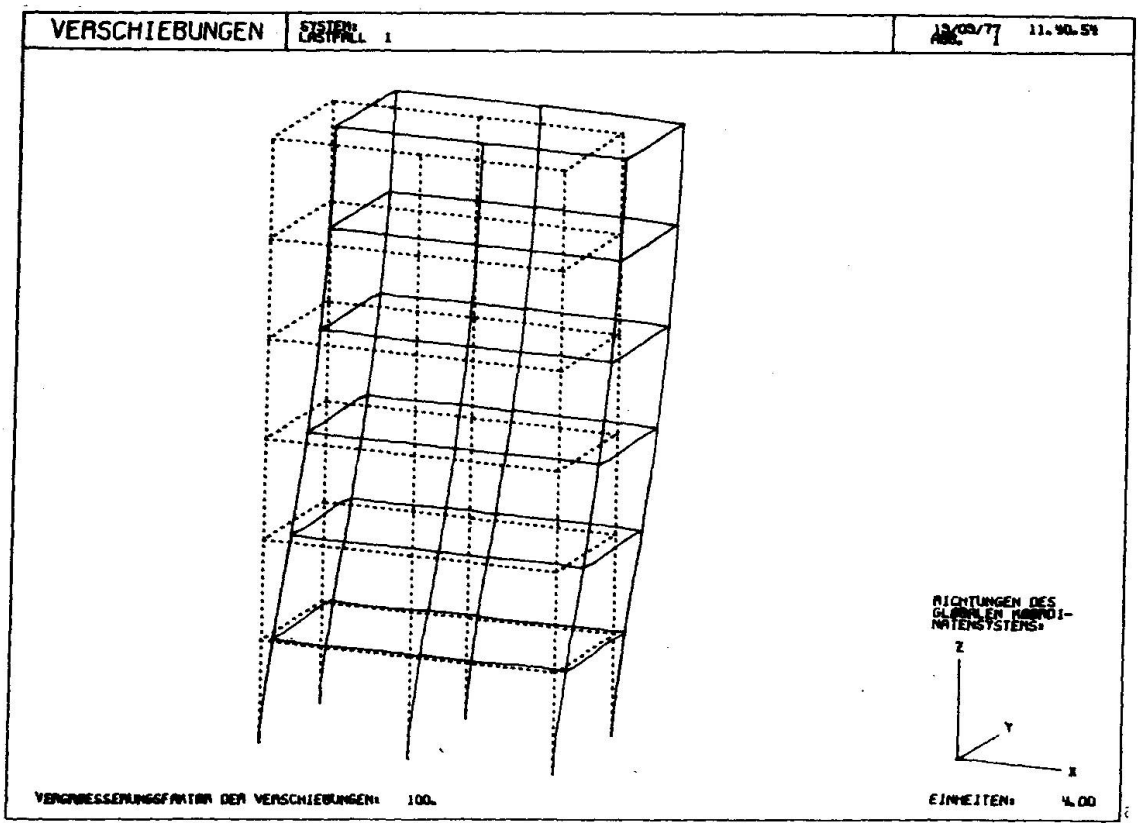

Fig. 8: Graphical output of the displaced shape of a multistory space frame.

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