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Personal Computer Systems in Nonlinear Analysis of Structures

Micro-ordinateurs dans l'analyse nonlineaire des structures

Anwendung von Personalcomputern zur Analyse nichtlinearer Strukturen

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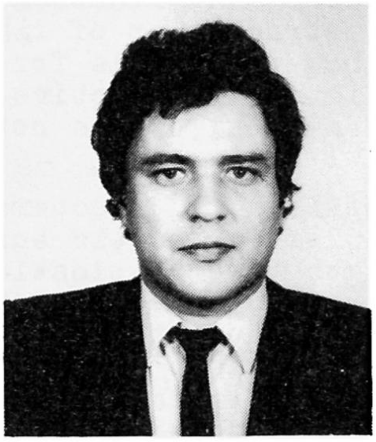

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SUMMARY
This paper presents a software package for the analysis of non-linear behaviour of bar structures modelled by means of non-dimensionalised Ramberg-Osgood curves. The incremental rigidity matrices are determined directly correcting the corresponding elastic matrices. The authors also present the results and conclusions arrived at on the basis of a numerical example.

RÉSUMÉ
Un ensemble de programmes pour l'analyse non-linéaire de structures en barres est présenté. Le comportement non-linéaire est modelé par des courbes sans dimension de type Ramberg-Osgood. Les matrices de rigidité incrémentales sont déterminées directement par correction de matrices d'élasticité. Les resultats et conclusions de l'étude sont présentés à l'aide d'un exemple numérique.

ZUSAMMENFASSUNG
Die Arbeit befasst sich mit Programmen für nichtlineare Substrukturen, modelliert durch dimensionslose Kurven des Ramberg-Osgood Typs. Die Steifigkeitmatrizen werden direkt durch Anpassung der elastischen Matrizen formuliert. Ergebnisse und Schlussfolgerungen werden anhand eines Berechnungsbeispiels verdeutlicht.

1. INTRODUCTION

Nowadays, in most countries - Romania included - structure calculation norms used in civil engineering resort to limit state design, which is considered to be more rational than permissible resistance design or fracture design. The limit state taken into consideration (serviciability limit state, elastic limit state, or plastic limit state) depends on the nature and the function of the building being designed. As far as frame structures are concerned, plastic limit state calculations ensure a rational and efficient design, regardless of whther the frames are made of reinforced concrete or steel. The introduction of limit state design in current design processes, however, calls for a nonlinear analysis procedure which is sufficiently effective from the technical point of view, but whose implementation does not pose great complications to the designer.

For instance, TWG 8.2 of ECCS [5] recommends the following calculation methods for the elastic-plastic analysis of steel structures: (1) ultimate strength theory (plastic zone theory); (2) second-order plastic hinge theory; (3) first-order plastic hinge theory. The first method is much too complicated to be used in current design processes, so that only the other two may be considered, keeping in mind their limitations as specified in the literature [5], [6]. As far as their implementation on microcomputers - equipment suited to design processes - is concerned, these methods have the drawback that they do not allow the direct determination of the incremental rigidity matrix; this is why the DISNABS (Dynamic and Static Nonlinear Analysis of Bar Structures) software package described in this paper implements a numerical method which allows the direct determination of the incremental rigidity matrix on the basis of Ramberg-Osgood nonlinear models of material (reinforced concrete or steel) behaviour [3]. This method considerably simplifies the computational algorithm, lowering memory requirements and increasing execution speed.

2. THE ASSUMPTIONS UNDERLYING THE COMPUTATIONAL ALGORITHM

The following assumptions underlie the nonlinear computational algorithm implemented in the DISNABS package:

- 1. Structures are made up of constant cross section straight bars.
- 2. The characteristic action-response diagram employed is of the same type for all the bars in a given structure.
- 3. Structure loading increases in direct proportion to the loading parameter .
- 4. Nonlinear analysis is based on first-order plastic theory, which gives up the plastic hinges hypothesis and takes into account the variable bending rigidity of cross sections along bars, which depends on loading and the real characteristics of the material the structures are made of. The nonlinear material-behaviour model is represented by means of the adimensional version of the Ramberg-Osgood M-ϕ diagram adapted to the type of material used in the given structure (Fig. 1, (a), (b), and (c)). This model enables the designer to take into consideration various material-behaviour laws formulated by means of the parameters μ and ρ (Fig. 1, (d) through (h)). If the sign of the bending moment changes in time - in the case of dynamic actions -, branching curves are used (Fig. 1, (i)).

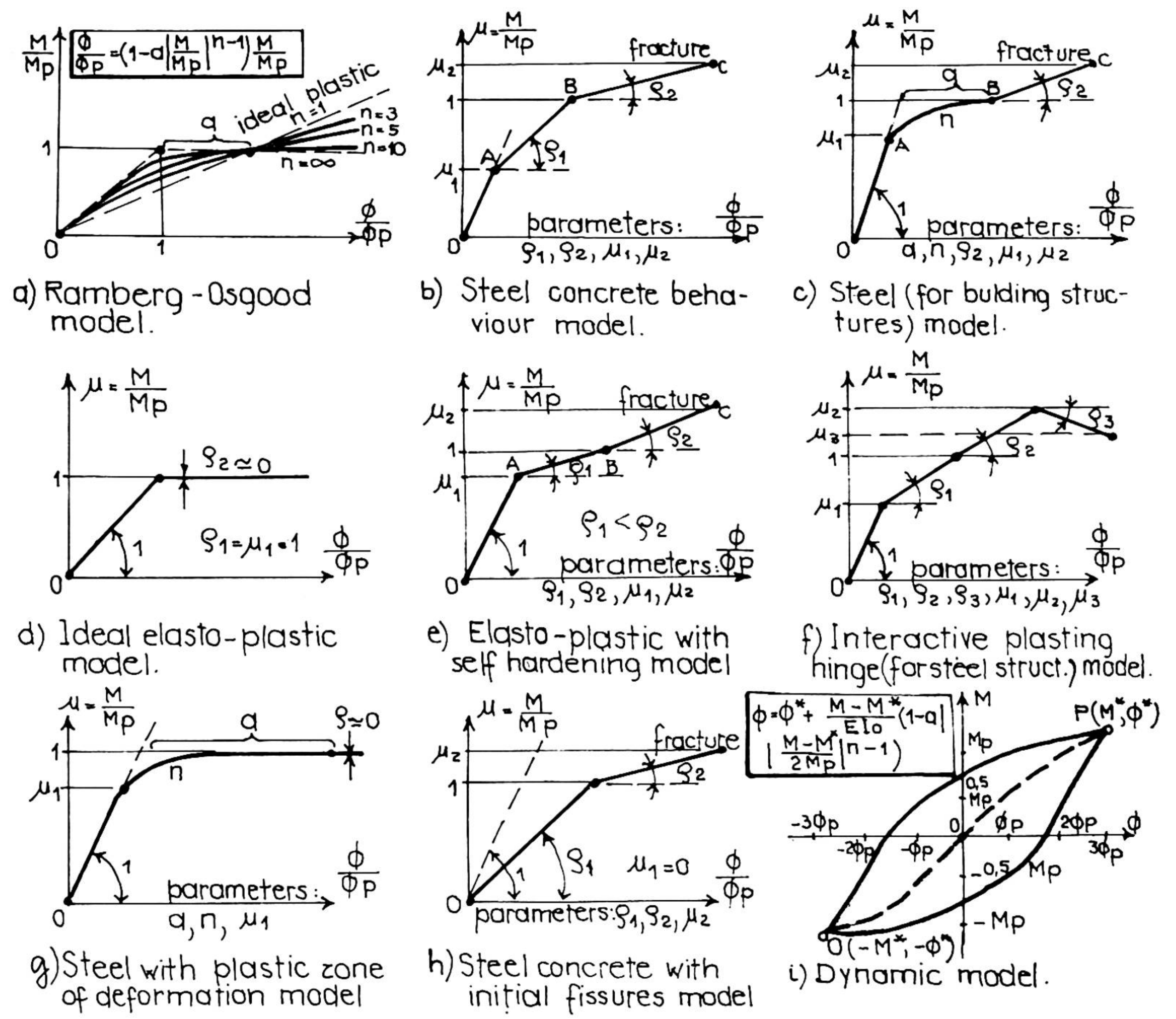

Fig. 1 Characteristic curves

- 5. The incremental rigidity matrices of the bars are obtained via the succesive-stage linearization of the M-Ø characteristic diagrams. The form of these matrices is similar to that of the rigidity matrices in elastic calculations; the former differ from the latter in that they display elements affected by nonelastic correction coefficients which take into account decreases in bending, axial, and torsional (for spatial structures) rigidity in each loading step. The way in which these correction coefficients are established is similar to that in which rigidity correction coefficients are determined for bars with variable cross sections in elastic calculations; for this purpose, each bar is divided into a number m of sections ($m \geqslant 30$).

- 6. Geometrical imperfections are considered to be related to the real deformation of the structure and are modelled by equivalent distributed loadings.

- 7. Residual tensions are taken into account via the initial decrease in the rigidity of the bars.

- 8. In dynamic analysis, the masses of the structures are assumed to be concentrated in the nodes, displaying translation inertia only. Under these circumstances, the dynamic rigidity matrix is obtained by condensing the D.O.F. corresponding to the rotations of the nodes.

- 9. In seismic analysis, vertical vibrations are ignored and the floors are assumed to be perfectly rigid in their plane.

- 10. The action-response hysteretic curves determined statistically do not change under low-speed dynamic loading.

- 11. Seismic movement acceleration varies linearly over incremental discrete time intervals Δt.

- 12. Nonstructural elements do not work together with the basic structure.

3. THE DISNABS SOFTWARE PACKAGE

The DISNABS software package, which is designed to be used on personal computers, performs the static and dynamic analysis of bar structures with nonlinear behaviour. The main functional characteristic of the DISNABS package consists in the fact that it allows the use of various M-Ø nonlinear curves, so that it can be used in the analysis of both steel structures and reinforced concrete structures. The characteristic curve is specified by the user via the input data, the package including an independent module, COEFC, by means of which one can determine the rigidity correction coefficients using the transfer matrices procedure, the parameters of the characteristic M-Ø curves being stored in a special-purpose file.

At present, DISNABS performs the static and dynamic analysis of three types of structures: plane frames, girder networks, and spatial frames. In order to deal with static problems, DISNABS includes a module for solving nonlinear equation systems that is based on a Newton-Raphson algorithm and offers the user three options when tackling a static problem: (1) the Newton-Raphson approach; (2) the modified Newton-Raphson approach; (3) incrementation with Newton-Raphson approach [2]. Dynamic (time-dependent) problems are solved by means of a Newmark-Wilson algorithm. The modular structure of the package makes it possible to create independent programs, one for each type of problems, a feature which ensures efficient memory management. Maximum program length is 64K.

Starting from the input data, which describe the topology of the structure, the type of M-Ø nonlinear characteristic curves, and loading, DISNABS presents the entire evolution of the stresses and displacements, throughout the successive calculation stages, until the carrying capacity of the structure is exceeded, either by fracturing or by exaggerated deformation.

The overall structure and organisation of the DISNABS package observe the same principles and the same functional diagram as the DISTAS package, presented in extenso in [4].

4. RESULTS

Figure 2 (c) shows the results obtained using the DISNABS package to analyze a frame (Fig. 2, (a)) for which eight M-Ø characteristic diagrams were given (Fig. 2, (b)). It was assumed that ΔP = 10 KN and $\underline{m}$ = 30. It is noted that in certain situations the ultimate state is reached via exaggerated deformation (relative limit gradient = 1/1,000), whereas in others via material fracture (elastic failure), at the base of the column on the right. In the case of the characteristic diagram no. 8, the results are close to those obtained applying first-order plastic hinge theory, P_{lim} = 260 KN.

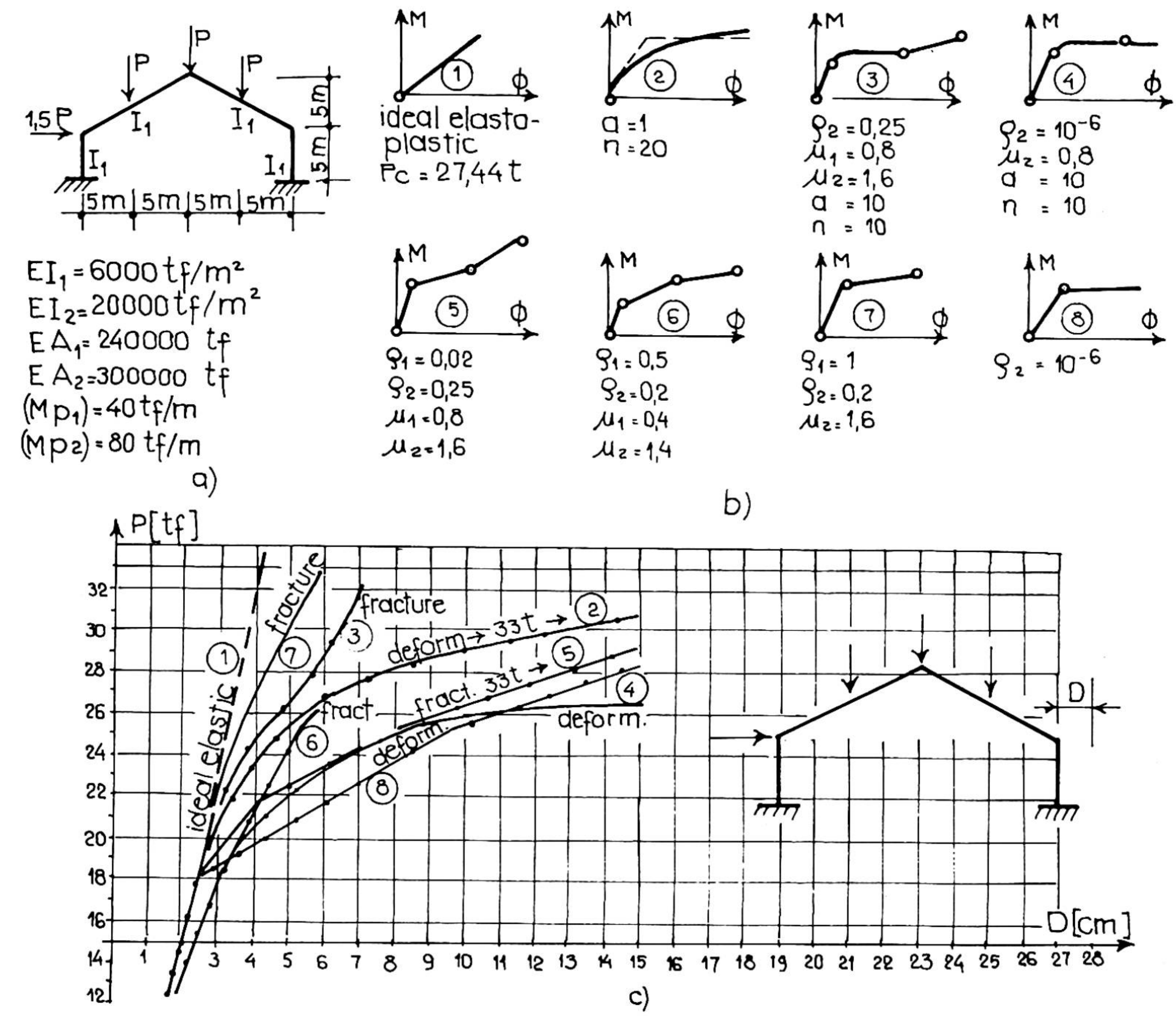

Fig. 2 Numerical example

The program was run on a SINCLAIR QL personal computer with 640K RAM (128K + 512K) and two 100K microdrives.

5. CONCLUSIONS

For reasons of space, it has not been possible to present at length the computational algorithm used and the performance characteristics of the DISNABS software package. The following general conclusions can nevertheless be drawn from the presentation above:

- 1. The DISNABS package performs the first-order plastic theory nonlinear analysis of bar structures, under both static and dynamic conditions, employing an algorithm that directly determines the incremental rigidity matrix.

- 2. The incremental rigidity matrices are determined by correcting the corresponding linear rigidity matrices.

- 3. DISNABS makes possible the differentiated analysis of structures by taking into account the materials they are made of.

- 4. The results obtained applying first-order plastic hinge theory are also yielded by an ideal elastic-plastic M-Ø model.

- 5. The DISNABS package is, according to its creators, a highly efficient calculation instrument when designing structures with elastic-plastic behaviour by means of the limit state method.

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