Gdańsk University of Technology
Civil and Environmental Engineering Faculty

"DISCO" – OBLICZENIA KONSTRUKCJI O PODPORACH CHARAKTERU CIĄGŁEGO I NIECIĄGŁEGO

"DISCO" – AN ANALYSIS OF STRUCTURES WITH CONTINUOUS AND DISCONTINUOUS SUPPORT CONDITIONS

"DISCO" – BEREKENEN VAN CONSTRUCTIES MET STEUNPUNTEN VAN CONTINU EN DISCONTINU KARAKTER

program manual

enclosure to doctor's thesis:
Contact problems in lock gates and other hydraulic structures in view of investigations and field experiences

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CONTENTS

1. DISCONTINUOUS FIXITIES – INTRODUCTION

This manual presents a computer program, DISCO, for the linear analysis of structures that may contain discontinuous fixities. These are fixities showing different linear behavior in various load ranges, e.g. tension-free supports of foundation grids, compression-free stays of cable-stayed bridges etc. The load-displacement diagrams of structures containing such fixities are polygonal lines rather than curves, which distinguishes them from non-linear structures – although some authors consider this property as a form of non-linearity. The program presented here has successfully been used in many projects of the author's engineering practice.

Although polygonal (or ‘piecewise-smooth’) behavior of structures is considered sometimes, e.g. Bathe [1], to be a form of non-linearity, there are authors, e.g. Szilard [2], who do not share this view. It will not be adapted in this manual either. Without entering into broad discussion on this matter, a strict distinction will be made between both terms. Let us consider a beam laid on some supports and loaded by its own weight *q*, a variable force *P* and a constant axial force *T*, as shown in Fig. 1. The beam supports are not fixed against vertical tension. This simple model can in principle be analyzed in 4 different ways which are shown underneath in a matrix form, see Fig. 1.

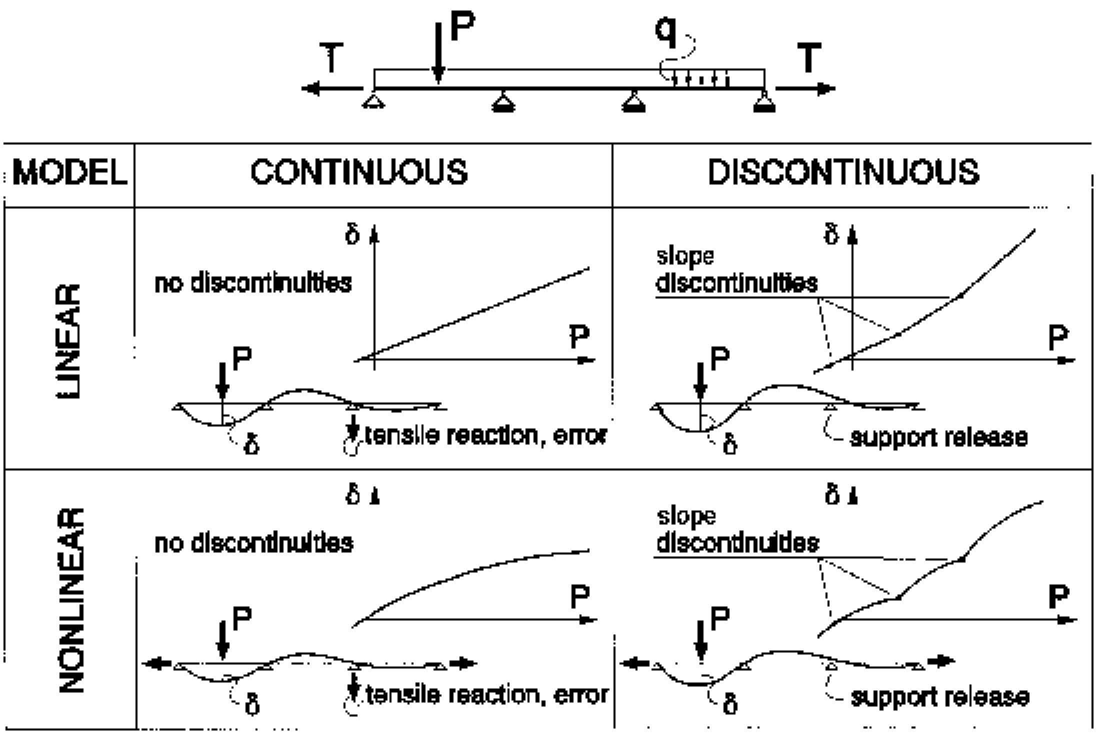


Fig. 1. Convention of (non)linearity and (dis)continuity assumed in this manual

Observe that the division into continuous and discontinuous behavior runs across the one into linear and non-linear one. The criterion is here a presence or an absence of slope discontinuities in the behavior functions of the structure, not a linear or non-linear character of these functions. Strictly speaking, the terms “continuous” and “discontinuous” are not quite correct here in the mathematical sense, as the functions *δ(P)* remain continuous in all the four cases. They are only not smooth in the right half of the matrix. These terms are, however, correct with respect to the first derivates (slopes) of these functions; and – above all – correct in the physical sense. Loosing contact with beam supports introduces material discontinuities in the system. In this – physical – sense we shall use these terms here.

In the considered example the continuous approach (both: linear and nonlinear) gives a tensile reaction on the third support, which is obviously an error. Moreover, there is another, quite principal argument in favor of discontinuous approach: Nature behaves in fact non-linear in a majority of problems. For no other reason than our own convenience, we often approximate it by using linear or piecewise linear approach. The family of problems dealt with by DISCO represents a rather exceptional, opposite case: Here the nature itself behaves piecewise linear (polygonal). There is no need to approximate it – it can be modeled the way it behaves. In mathematical sense, polygon angles are slope discontinuities. Therefore, we will refer to them as "discontinuities". In engineering, it is quite usual to refer in such a way to sudden, sharp changes in structure properties, without explicit mentioning the word 'slope', see e.g. discussions on joints in shells of revolution by Roark [3] or by Bull [4]. In this sense one can distinguish various types of discontinuities (or: discontinuous fixities):

- *external*: e.g. discontinuous support conditions;
- *internal*: e.g. ties or unfixed contacts between elements;
- *mechanical*: caused by geometry or mechanical properties;
- *physical*: caused by material properties, e.g. plastic hinges;
- *fractural*: irreversible, caused by breakage, etc.

The DISCO algorithm presents a solution for structures with external discontinuities. An extension for internal discontinuities and some other problems is possible and will briefly be discussed later on.

Engineering practice proves that a great majority of discontinuities occur at transition points between negative and positive fixities of diverse degrees of freedom (DOF's). For clarity reasons this analysis is limited to such cases. It is, however, a minor problem to program the levels of discontinuity as input data, so that other than zero transition points can be defined. Such modification requires no further changes to the presented algorithm.

In Fig. 2 a number of polygonally linear problems have schematically been shown. Cases **a** until **f** represent discontinuous fixities of reaction forces in various directions; cases **g** and **h** are examples of discontinuous moment fixities. A short description follows below.

a. Suspensions of pipelines, tie-rod fixities of expansion joints;
b. Rails, crane driveways with limited tension fixities;
c. Cable stayed bridges, bustle pipes of steel works blast furnaces;
d. Cable stayed masts, towers, halls etc.;
e. Support rings e.g. of vertical pressure vessels, free laid foundation grids;
f. Concentrated loads on refractory lined oven shells, traffic tunnels etc.;
g. Single-sided moment fixities of columns and beams, torsion fixity of a blade;
h. Examples of discontinuous moment fixity in reinforced concrete.

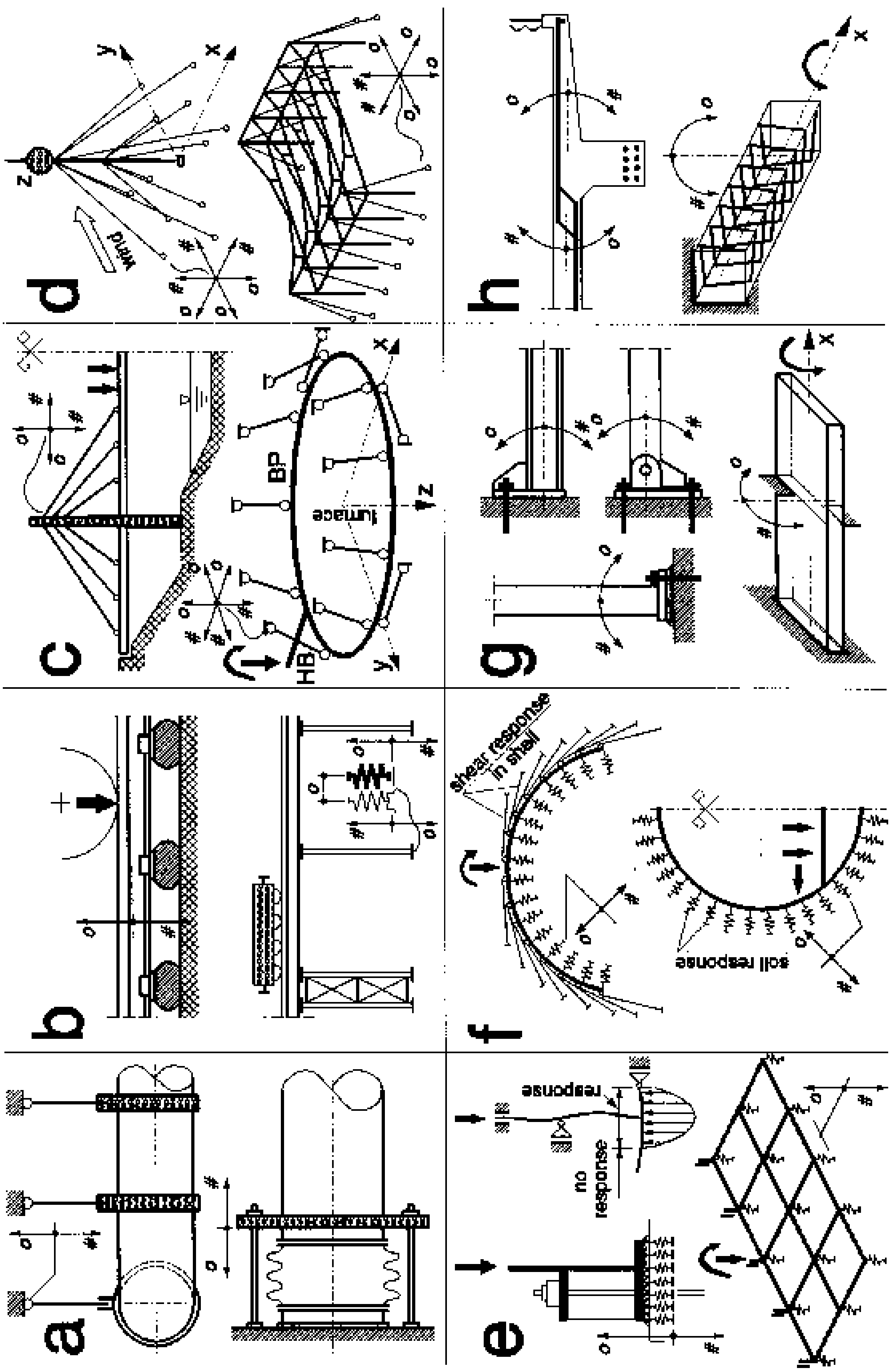


Fig. 2. Examples of discontinuous fixity problems

2. MODELING DISCONTINUOS FIXITIES

Note that all discontinuous fixities can be modeled by defining a "conditional" DOF, e.g.:

- force: tension fixed (#), compression free (**0**) – or reverse;
- moment: clockwise fixed (#), anti-clockwise free (**0**) – or reverse.

This also applies to DOF's that are not simply fixed or free, but that show different positive and negative fixity characteristics. The solution is then an additional, conditionally fixed element in the direction of the considered DOF. This method can be illustrated by the three following examples (see Fig. 3).

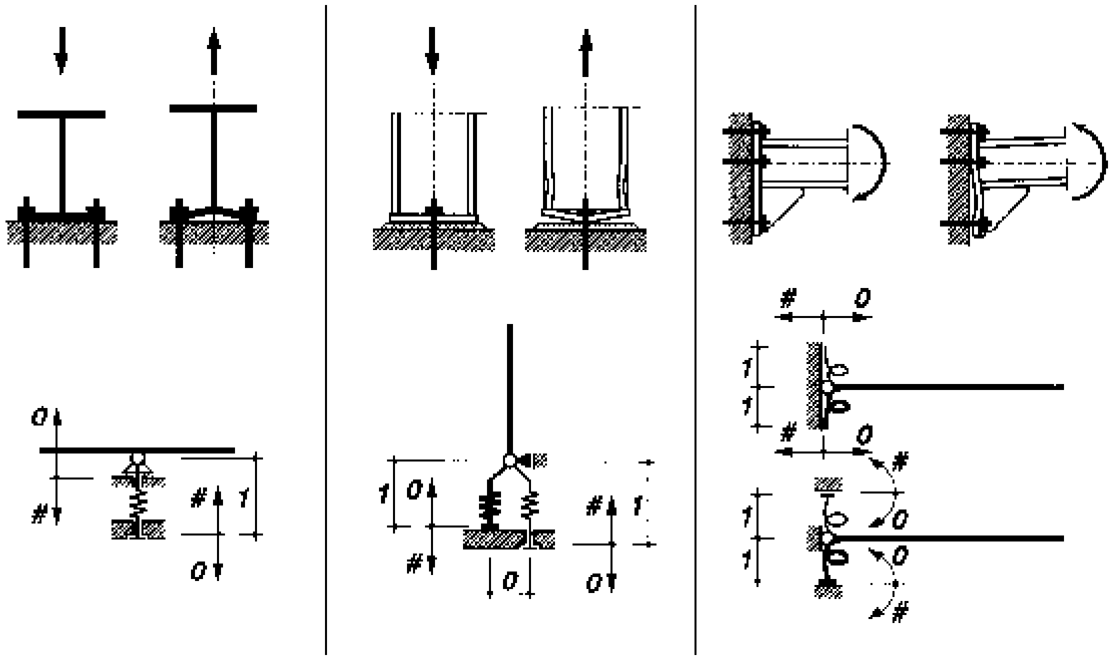


Fig. 3. Modeling different fixity characteristics

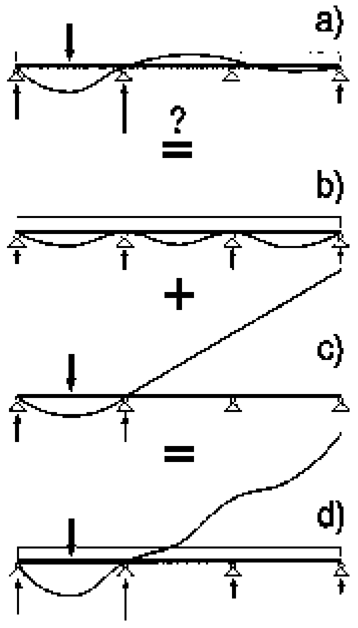
In the first example a conditional spring has been used to model the elastic tension fixity of a beam support. In the second example two conditional springs represent different fixity characteristics of a column base. (Note that the node coordinates of these springs can in fact be identical, as long as no connection between them is defined.) The third example shows two ways of modeling discontinuous moment fixities. In that example, the two conditionally supported springs can optionally be fixed against displacement or against rotation.

This technique applies also to 3D-models where the number of conditional DOF's can be larger. The limitation of the algorithm is, however, that only point-wise fixities can be defined in this way. A conditional line- (or surface-) support becomes released over a certain distance (or area) what makes the solution more complex. This can be solved by defining a number of conditional point-wise supports in a line or over a surface. Such models are in fact powerful tools in solving numerous structural contact problems[1)] (see e.g. Fig. 2 **e** and **f**), what has been illustrated in a practical case in section .

[1)] Contact problems have been studied broadly in recent years. A linear incremental approach to such problems has e.g. been presented by Simunovic and Saigal in [5]. Other approaches can e.g. be found in the works of Refaat and Meguid [6] or Wang and Nakamachi [7].

3. PROPERTIES OF DISCONTINUOUS LINEAR MODELS

Polygonally-linear (here called "discontinuous") models have some special properties which distinguish them from conventional, smooth-linear ("continuous") models. The most favored property is, obviously, that they allow for more adequate structural analyses. Having seen the examples in Fig. 2 and 3, it would not be wrong to say that most structures behave more or less polygonally. The fact that they are usually subject to 'smooth' modeling can be justified by limited precision requirements, narrow ranges of load variation, our convenience, tradition etc.



The second property is a warning: Separately computed load cases should, as a rule, not be combined! The principle of superposition should be considered false in discontinuous analyses. Observe what happens to the beam from the beginning of this manual (Fig. 1) when separately computed load cases are combined (Fig. 4). The superposed deflected line and reactions (**d**) strongly differ from the correct ones (**a**) and are mutually inconsistent.

In consequence, complete load combinations should each time be computed, rather than computing single load cases and combining the results. This property is important not only to the program users but also to the programmers. A complete discussion on this subject goes beyond the scope of this manual. Nevertheless, it's significance must de emphasized because superposition is one of the elementary procedures in structural analyses.

Fig. 4. Superposition results in an error

Let us confine the discussion to the three following recommendations:

1. The conventional programs for continuous structural analyses contain procedures to combine single load cases in load combinations – usually with user defined combination factors. These procedures should not be programmed (neither be used) for discontinuous linear analyses.
2. Most existing structural analysis programs make use of two separate input files called, e.g., *system file* and *loading file*. In discontinuous analyses - as already discussed - loadings actually co-define the systems. For the sake of consistency they should better make part of one integral input file.
3. Several existing programs do not allow to set concentrated loads on supports in the directions of fixity. It is assumed that such loads are irrelevant since they pass directly to reactions causing no strain effect in a system. This is not necessarily true in discontinuous models. The programs for discontinuous analyses must enable the input of those loads.

Obviously, the importance of loadings in discontinuous linear models requires more care to their input. One should, e.g., be cautious in using load factors, which is a common engineering practice nowadays. Increasing a load factor e.g. for variable loads does not necessarily lead to a safer structure. There is a chance that a number of nodes get released or fixed after such operation, what may not be the intention.

The last property in this short overview concerns stability: Discontinuous linear models require more consideration to stability problems, providing in return a more reliable stability test. Models which become unstable, e.g. due to single-sided support releases, cannot be computed. A program should issue a warning in such a case. On the other hand, properly modeled discontinuous linear structures that are successfully computed are also certainly stable.

4. SOME THEORETICAL BACKGROUND

Let’s consider a structure model meeting all Clapeyron’s conditions [8] and supported by a number of point-wise external fixities (of forces and/or moments). Let’s assume that some of those fixities or all of them are conditional (discontinuous) in the sense as discussed above. Since it is not known which single-sided fixities will be active and bear reactions, and which will be released - there is no way to solve this discontinuous linear model directly. A solution must involve an iteration process eliminating released fixities and converging in a model with a definite, ‘smooth’ fixity system. At each step of such iteration an entire - let's call it after Ralston [9] - *basic solution* of the system must be computed.

A ‘classical’ nonlinear approach to such problems, as discussed e.g. by Bathe [1] (new supports arising during structure deformation), considers the externally applied loads - thus also deformations, stresses etc. - to be a function of time. The resulting approach is an incremental step-by-step procedure using the solution for discrete time t to compute the solution for discrete time $t + \Delta t$. Aside from the plea against nonlinear approach as such (see Introduction), there are several practical reasons why this strategy has been rejected here. For the space reasons, they are not discussed. Some of them (e.g. error accumulation, inconvenience of time functions) will become clear further in this manual.

The proposed algorithm of solution can, in the simplest terms, be described as follows:
1) Convert the structure model in such a way that all conditional (single-sided) fixities become unconditional (double-sided). Memorize conditional fixities in the original model.
2) Solve the converted model for the entire load combination, computing the vector of node displacements $\boldsymbol{D}$ and the vector of node external reactions $\boldsymbol{R}$.
3) Check if every $R \neq 0$ reaction occurs on the fixed side of a proper conditional DOF in the original model. Each time it does not; modify the converted model by releasing the particular DOF.
4) Check if every $D \neq 0$ displacement occurs on the free side of a proper conditional DOF in the original model. Each time it does not; modify the model by fixing the particular DOF.
5) If step 3 or 4 result in any modification, go to step 2. Otherwise the system is solved.

The question concerning step 1 is why to convert the single-sided DOF’s into double-sided. In general, two ways can be considered to convert a discontinuous model into a continuous one[2]. Let us call them:
- *Stiff approach*: replace all single-sided fixities by double-sided;
- *Slack approach*: release all single-sided fixities.

A disadvantage of the *slack approach* is that it may produce an unstable model during the iteration. This endangers the convergence. The *stiff approach* does not bear that risk. Another possible question is why to bother checking the sides of displacements in step 4. One might suppose that – since the *stiff approach* has been used – it is the releasing of the DOF’s that leads to the solution, not the fixing. This proves not to be sufficient. A DOF that has once been released may require to be fixed again in one of the next iteration steps. As far as this approach has been researched, there exists no convergent iteration that solves the problem using only irreversible DOF modifications.

Naturally, it should be proved that the procedure shown above is convergent. From the engineering point of view, however, an instructive example is often more convincing than a strictly theoretical discussion. A simple model enabling to observe the features of the algorithm in a transparent way is a weightless beam on a large number of rigid, tensionless supports, loaded by a single force in the middle of one span. In Fig. 5 a half of such a beam has been modeled due to the system symmetry[3].

[2] A third, "middle way" is also thinkable if additional precautions are taken to ensure the convergence. This might lead to further perfectioning of the algorithm. It has not been investigated so far.

[3] This example requires an exceptionally large number of iterations. This and the problem triviality are chosen deliberately to picture some features of the procedure. It must not be seen as a sign of its small efficiency.

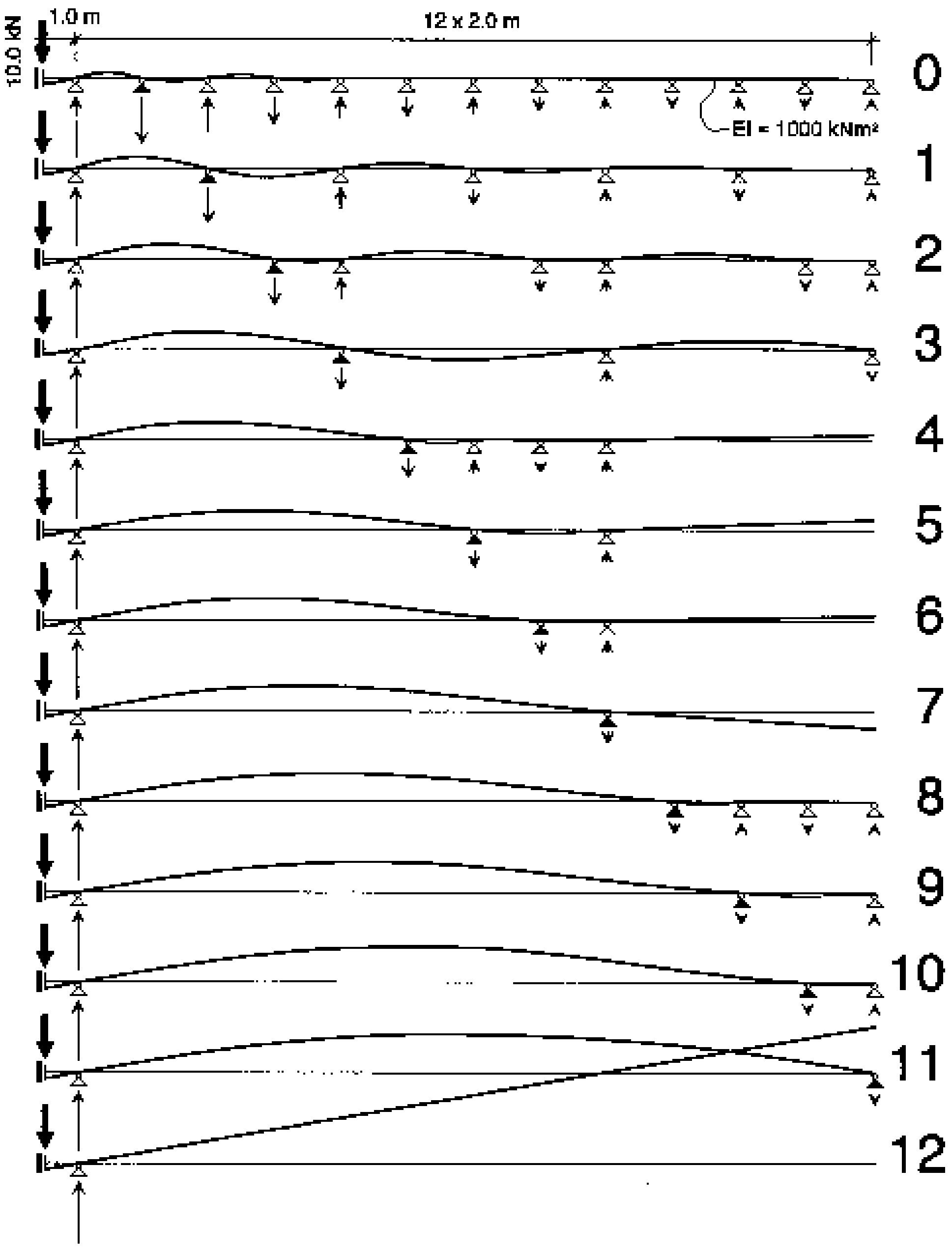


Fig. 5. Iteration steps for a beam on tensionless supports – example

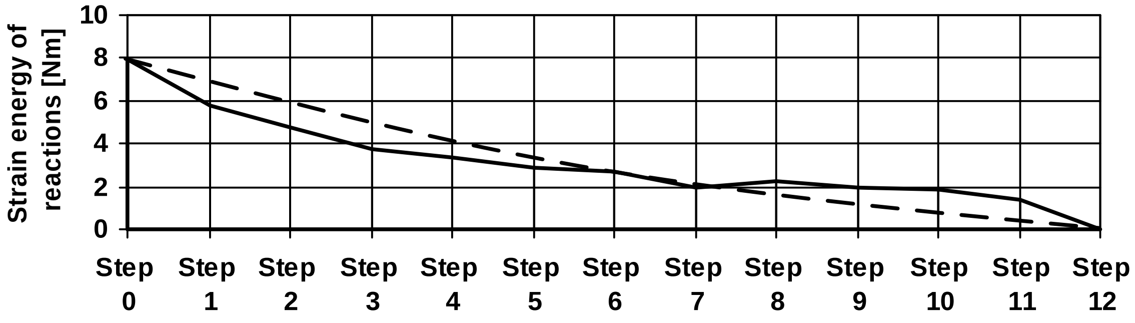


Fig. 6. Strain energy of reactions in the 12 iteration steps
(Energy level 0 equals here in fact 16.7 Nm, see calculations in the text)

As known, the solution of such a system is a free-supported one-span beam. The way, in which the algorithm described above comes to this solution, has been shown in steps 0 through 12. Note that each step results in eliminating (sometimes also in adding) of a number of supports from which at least (here always) one is eliminated definitely. That one support has each time been marked black in the drawing. Note also that the supports guaranteeing the stability of the system (here just one) are not eliminated at any step. These two features of the algorithm have been confirmed in a large number of tests on different systems. They are sufficient to make the procedure convergent.

We shall now follow the changes of strain energy "bound" by reactions in this iteration process. It is convenient to do it in reverse order, in which we expect this energy to grow. Let's consider two neighboring iteration steps ***i*** and ***i***-1; and sign by ***j*** the joint (node) numbers of the beam. From the reciprocal theorem of Betti-Maxwell [8] we have:

$$\sum_{j=1}^{n}\left(P_j + R_{i,j}\right)d_{i-1,j} = \sum_{j=1}^{n}\left(P_j + R_{i-1,j}\right)d_{i,j}\ .$$

By proper modification of this equation we can obtain a double formula for work $L_{i\circledR\ i\text{-}1}$ required to bring the beam from the deformation state in step ***i*** back to the step ***i***-1:

$$L_{i\to i-1} = \frac{1}{2}\sum_{j=1}^{n}\left(R_{i,j}d_{i-1,j} - R_{i-1,j}d_{i,j}\right),$$

$$L_{i\to i-1} = \frac{1}{2}\sum_{j=1}^{n}P_j\left(d_{i,j} - d_{i-1,j}\right).$$

Since there are many reactions R_j and just one force P_j in our example, the easiest way to obtain strain energy variation is through the second of these two equations. Starting from step 12, where the computed deflection under force ***P*** was δ = 3.33 mm, we obtain:

step 12, δ = 3.33 mm:	$L_{12} = \frac{1}{2}\times 10\times 3.33\times 10^{-3} = 16.7\times 10^{-3}$ kNm,
step 11, δ = 3.05 mm:	$L_{12\to 11} = \frac{1}{2}\times 10\times(3{,}33-3{,}05)\times 10^{-3} = 1.4\times 10^{-3}$ kNm,
	$L_{11} = (16.7+1.4)\times 10^{-3} = 18.1\times 10^{-3}$ kNm,
. . .	. . .
step 0, δ = 1.75 mm:	$L_{1\to 0} = \frac{1}{2}\times 10\times(2.17-1.75)\times 10^{-3} = 2.1\times 10^{-3}$ kNm,
	$L_0 = (22.5+2.1)\times 10^{-3} = 24.6\times 10^{-3}$ kNm.

The strain energy variation calculated in this way has been shown in a diagram in Fig. 6. There are some interesting features to be observed in Fig. 5 and 6, namely:

- One can see that the elimination of the released DOF's takes place in a quite regular, 'frontal' manner bearing, in this respect, some resemblances to other known elimination processes, e.g. to the Gauss elimination.
- The DOF fixity, which becomes definitely eliminated, is here always the one, which "binds" the biggest strain energy. In more complex systems this will apply to certain groups of DOF's rather than the single DOF's; which can make it less visible.
- We see that the total number of fixed DOF's does not always become smaller at every step. Neither the total strain energy of these DOF's does always become smaller. See, e.g., the transition from step 7 to step 8. Yet, this does not endanger the convergence.

- The variation of the total strain energy of the fixed DOF's can globally be approximated by a concave curve (arc convex downward). The energy losses in the first iteration steps are usually the biggest. This favorable property will still be discussed.
- The approximation by a concave curve shows here an interesting irregularity, which can – for the present – be called an *energy wave*. This has not been studied any further. It has, however, been observed that this phenomenon becomes less visible in models on elastic instead of rigid supports. This leads to some analogies with damping.

Finally, let's observe that a nonlinear approach using time functions would be useless for this problem. Time is irrelevant since any force P acting downwards gives basically the same solution (P directed upwards gives instability). For the same reason also the term *polygonal approach* may be controversial for this load case. Yet, since weightless beams are quite exceptional, we shall drop that detail.

5. CODING DISCONTINOUS FIXITIES

Since every step of the iteration computes an entire *basic solution* of the system, the method can be considerably time-consuming. Therefore, it is advisable to use a quick, simple procedure for the basic solution, even at the cost of diversity of modeling features[4]. The algorithm of the DISCO program has been developed for PC applications. The program itself [10] - uses a basic solution where the following limitations and other assumptions have been applied:

- Structure model consists of straight, one-dimensional elements (members). Shells, plates etc. can not be modeled directly and must be simulated using members.

- All structure elements have default rigid or pinned nodes (joints) between each other, depended on the type of the structure: Trusses are assumed to have pinned joints, all other structures are assumed to have rigid joints. Modeling a hinge, a slide joint etc. in a structure of default rigid joints (e.g., a frame) can be done using simulation members.

- User can choose between the following 12 types of structures[5]:

1	Continuous beam;	**2**	Discontinuous beam;
3	Continuous plane truss;	**4**	Discontinuous plane truss;
5	Continuous grid;	**6**	Discontinuous grid;
7	Continuous plane frame;	**8**	Discontinuous plane frame;
9	Continuous space truss;	**10**	Discontinuous space truss;
11	Continuous space frame;	**12**	Discontinuous space frame.

- Loadings can be concentrated (forces and/or moments in joints) or distributed over an entire member length. All loads are stored in the same data files as the system data. Joint loads in externally fixed directions are acceptable.

- Every joint can, in principle, be loaded by a pointed load (force or moment) in any direction, but – on the other hand – to input such a load one must first define there a joint. Also every member can carry a distributed load in any direction, but is assumed to be equally distributed over the entire member

[4] The discussed software was originally developed in the 1980's, when memory consumption and computation time were of more significance than they are today.

[5] For continuous models similar divisions have been used in some early structural analysis programs, e.g. STRESS [11], ICES STRUNDL [12]. Such approach leads to a quick, memory saving basic solution.

length. To input an unequally distributed load or a load covering a part of a member length, one must first divide the member into sectors by defining more joints.

- The result of the basic solution is a vector ***D*** of all joint displacements; and a vector ***R*** of all joint reactions. Both vectors are appropriate to the structure type and related to the global orthogonal XYZ axes. The form of both vectors is the same. The displacements ***D*** are:

• in beams:	displacements D_Y,	rotation angles A_Z;
• in plane trusses:	displacements D_X, D_Y;	
• in grids:	displacements D_Z,	rotation angles A_X, A_Y;
• in plane frames:	displacements D_X, D_Y,	rotation angles A_Z;
• in space trusses:	displacements D_X, D_Y, D_Z;	
• in space frames:	displacements D_X, D_Y, D_Z,	rotation angles A_X, A_Y, A_Z.

  In the vector ***R*** of reactions, the forces *R* come in place of displacements *D*, and the moments *M* come in place of rotation angles *A*. All indices remain the same.

- Joint external fixities (supports) are identified by joint types. Every combination of joint fixed and free DOF's has a unique (within the structure type) joint type number. This applies to continuous as well as discontinuous structures. In the latter, the number of combinations is much larger.

Coding joint types is one of the crucial points of the entire algorithm. Note that each single DOF can be:

If *continuous*:	If *discontinuous*:
1. free;	1. free on positive and on negative side;
2. fixed.	2. free on positive, fixed on negative side;
	3. fixed on positive, free on negative side;
	4. fixed on positive and on negative side.

Since the number N_D of joint DOF's varies from 2 for beams to 6 for space frames, the number N_T of possible joint fixity combinations (= joint types) will vary still stronger. This has been shown in Table 1:

Table 1. Numbers of joint types in different types of structures

	No. (N_D) of DOF's	No. (N_T) of joint types **Continuous**	**Discontinuous**
Beam	2	$2^2 = 4$	$4^2 = 16$
Plane truss	2	$2^2 = 4$	$4^2 = 16$
Grid	3	$2^3 = 8$	$4^3 = 64$
Plane frame	3	$2^3 = 8$	$4^3 = 64$
Space truss	3	$2^3 = 8$	$4^3 = 64$
Space frame	6	$2^6 = 64$	$4^6 = 4096$

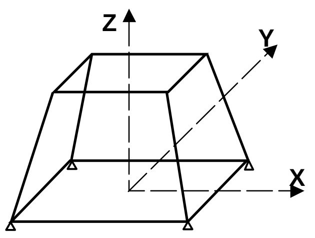
Let's assume that type no. 1 represents a joint with all DOF's free, i.e. no external fixities; and type no. N_T represents a joint with all DOF's fixed. The procedure described below shows the way to determine any joint type from the range [1..N_T][6]:

[6] The Pascal notation for ranges is used in this manual. A notation [***a***..***b***] means here (***a*** ÷ ***b***) or ***a*** till ***b***, included. The DISCO software has been developed by the author in Turbo Pascal® of Borland International Inc.

1. Make a table for the type of structure under consideration, with in the headline all DOF's as listed earlier in this section. The tables for discontinuous structures should have double ("positive" and "negative") columns under each DOF. In the most complex case of a space frame, the headlines of such tables should be similar to the ones shown in Table 2.

Table 2. Examples of joint type determination in 3D-frames

- Continuous space frame:



Joint	D_X	D_Y	D_Z	A_X	A_Y	A_Z		Type
no.	2^5	2^4	2^3	2^2	2^1	2^0		no.
26		#		#		#	+1=	22
58	#	#	#				+1=	57
134	#	#	#	#	#	#	+1=	64

- Discontinuous space frame:

Joint	- D_X +		- D_Y +		- D_Z +		- A_X +		- A_Y +		- A_Z +			Type
no.	2^{11}	2^{10}	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0		no.
25	#	#	#	#	#	#			#				+1=	4041
129		#		#		#							+1=	1345
138	#	#	#	#	#	#	#	#	#	#	#	#	+1=	4096

2. Assign to each column an integer value varying...
   - for continuous models: from 2^{N_D-1} down to 2^0,
   - for discontinuous models: from 2^{2N_D-1} down to 2^0,

   as shown for space frames (N_D = 6) in the table headlines above (Table 2).

3. List all the fixed joints (supports) of the considered model in the left column; and check the cells representing joint fixities e.g. by #. The sums of values assigned to the checked cells, increased by 1, represent the joint types[7].

It is not difficult to see resemblances to the binary system in this coding. An advantage of such coding in computer programming is that it enables the use of very quick, bit-level operations for all the transitions from discontinuous to continuous fixities (joint types), and for all the modifications of joint types in the iteration process[8]. The details of this will be discussed in the next section.

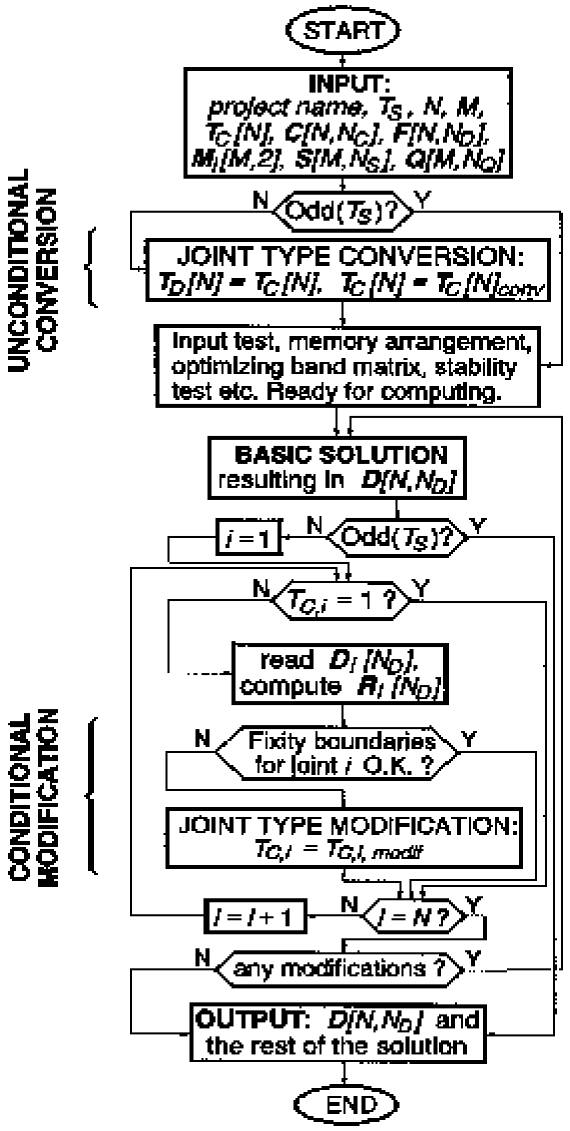
[7] In a computer program this procedure can e.g. be realized by using overlay windows. Checking 'fixed' cells can then take place by a mouse click.

[8] In the past the binary code was used much wider to program the analyses of complex structural problems. An impressing example of such notation can e.g. be found in [13]. This is, obviously, not the case here any more.

6. PROGRAMMING APPROACH

6.1 Program environment

In order to minimize the computation time, it is important to choose an optimal program environment. It is, e.g., not advisable to incorporate time consuming operations on files (opening, reading, writing etc.) in the iteration process. On the other hand, it is certainly advisable to use, e.g., band matrix optimization[9]. Fig. 7 presents a flow chart of a software environment, as programmed in DISCO, incorporating the algorithm for discontinuous analysis. Flow charts of the actual algorithm will be shown later on.



START
INPUT: project name, T_S, N, M, $T_C[N]$, $C[N,N_C]$, $F[N,N_D]$, $M_i[M,2]$, $S[M,N_S]$, $Q[M,N_Q]$
N Odd(T_S)? Y
JOINT TYPE CONVERSION: $T_D[N] = T_C[N]$, $T_C[N] = T_C[N]_{conv}$
Input test, memory arrangement, optimizing band matrix, stability test etc. Ready for computing.
BASIC SOLUTION resulting in $D[N,N_D]$
$i = 1$
N Odd(T_S)? Y
N $T_{C,i} = 1$? Y
read $D_i[N_D]$, compute $R_i[N_D]$
N Fixity boundaries for joint i O.K. ? Y
JOINT TYPE MODIFICATION: $T_{C,i} = T_{C,i,\,modif}$
$i = i + 1$
N $i = N$? Y
N any modifications ? Y
OUTPUT: $D[N,N_D]$ and the rest of the solution
END
UNCONDITIONAL CONVERSION
CONDITIONAL MODIFICATION

The notation used in this flow chart may require an explanation:

- N and M are total numbers of, respectively, joints and members.
- N_C, N_D, N_S and N_Q are integer constants depending on structure type T_S and helping to format proper matrices. They represent the characteristic numbers of, respectively: joint coordinates, joint DOF's (equal to possible concentrated loads), member sectional stiffnesses and member distributed loads. These constants are given in Table 3.

Table 3. Matrix formatting constants depending on structure types

T_S	Structures	N_C	N_D	N_S	N_Q
1, 7	Beams	1	2	1	1
2, 8	Plane trusses	2	2	1	0
3, 9	Grids	2	3	2	1
4, 10	Plane frames	2	3	2	2
5, 11	Space trusses	3	3	1	0
6, 12	Space frames	3	6	4	3

Fig. 7. DISCO – general flow chart

Table 3 helps also to understand why a division into structure types has been used in DISCO. Modern FEM programs offer a number of element types to be used in a model rather than conforming the model to one element type. However, in iterative algorithms where the entire *basic solution* must be computed a number of times, it is preferable to use simple models. In particular, the low numbers of DOF's N_D and sectional stiffnesses N_S in models simpler that 3D-frames speed the computing considerably up. It

[9] Band matrix optimization falls beside the scope of this manual. DISCO uses an own, simple optimization method. A good introduction to more complex, so-called fractorization methods can e.g. be found in [9].

also keeps the band matrix [14], [15] narrow, limitting the memory consumption. Further, the following features should be observed in the flow chart in Fig. 6:

- The entire input data for each run (loading case) is contained in one input file. No division into, e.g., *system* and *loading files* has been made. According to the discussion in section 3, no procedures combining single loading cases into complex, superposed cases have been programmed.

- In the input data, the loadings have the same status as the so-called system data. Vector $\boldsymbol{F}_i[N_D]$ of joint i concentrated loads comes in fact right behind the vector of joint coordinates $\boldsymbol{C}_i[N_C]$. Vector $\boldsymbol{Q}_j[N_Q]$ of member j distributed loads follows the vector of member stiffnesses $\boldsymbol{S}_j[N_S]$.

- In case of odd type number T_S (see structure types earlier in this manual), the structure is continuous and there is no need for iteration. The first approach leads directly to the solution. In case of even T_S , the structure is discontinuous. It is first converted into a continuous structure. After the band matrix optimization, it undergoes an iteration process with joint type modifications at every step, converging in a solution that meets all discontinuous fixity conditions.

- The iteration process is memory- and time-saving. Note that no operations on files are involved. The vector of joint reactions $\boldsymbol{R}_i[N_D]$, which rules the process along with joint displacements $\boldsymbol{D}_i[N_D]$, becomes only computed for the joints of types $T_{C,i} > 1$; and always to the same memory space.

- Compared to “continuous programs”, the flow chart in Fig. 7 contains only two really new blocks, marked *unconditional conversion* and *conditional modification*. These blocks represent the essence of the algorithm and will be discussed further in this section.

- With the exception of discontinuous analysis, this approach does not differ much from some early programs for skeletal structures, e.g. STRESS [11]. However, it is a minor problem to adapt it to a more complex FEM environment.

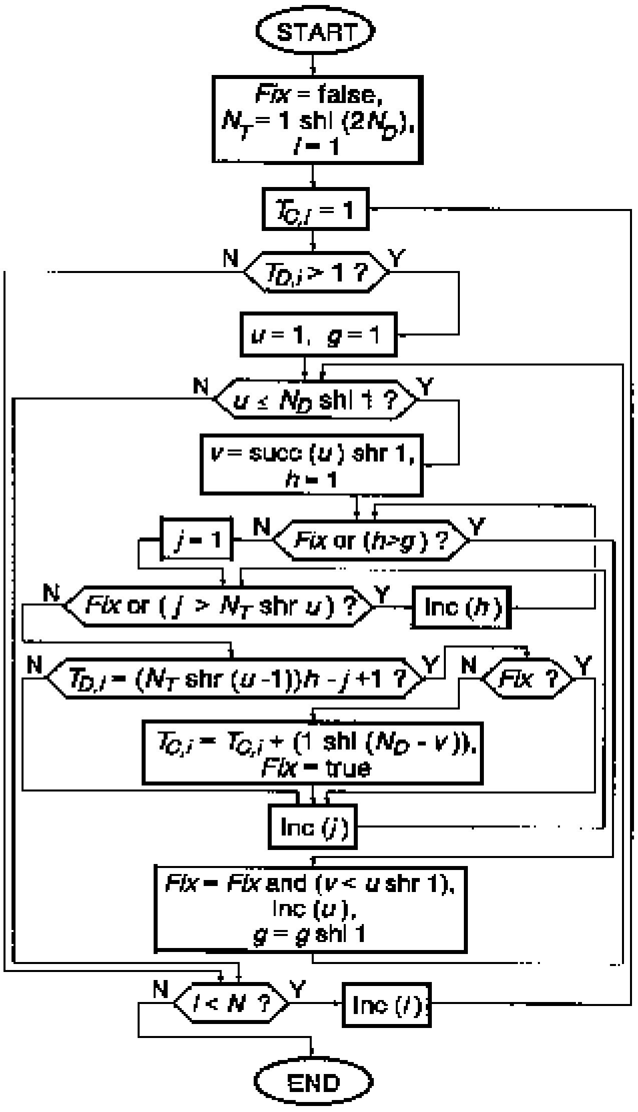
The block *unconditional conversion* converts all discontinuous joint types $\boldsymbol{T_D}[N]$ into continuous ones $\boldsymbol{T_C}[N]$[10]. As result the structure model becomes in fact Continuous. The vector of discontinuous joint types $\boldsymbol{T_D}[N]$ remains in memory for the boundary tests at each step of the iteration.

These tests are performed in the block *conditional modification*. The tested objects are vectors of joint reactions $\boldsymbol{R}_i[N_D]$ and displacements $\boldsymbol{D}_i[N_D]$. In general, the procedure investigates whether reactions have only been computed on the fixed sides, and displacements on the free sides of single-sided supports. Each time the answer is "no" a proper DOF gets released, respectively fixed for the next iteration step.

6.2 Unconditional conversion

Unconditional conversion defines the initial model for the iteration. All discontinuous joint types $T_{D,i}$ are replaced by continuous types $T_{C,i}$ in such a way that fixity on any side (+ or -) of a considered DOF qualifies this DOF as fixed. This procedure is shown in a flow chart in Fig. 8. It does not make part of the iteration process and is only executed once at the beginning of the program. Nevertheless an effort has been done to minimize the computation. One of the measures applied is the introduction of a logical variable *Fix* which provides exits from different loops as soon as their tasks are completed.

[10] Converting into continuous types means here converting into type coding of a continuous model, using the *stiff approach*. E.g., the type number of an entirely fixed (i.e. in fact continuous) joint of a discontinuous space frame changes from $T_{D,i} = 4096$ into $T_{C,i} = 64$, see examples in section 5.


START
Fix = false, N_T = 1 shl (2N_D), i = 1
T_C,i = 1
N
T_D,i > 1 ?
Y
u = 1, g = 1
N
u ≤ N_D shl 1 ?
Y
v = succ (u) shr 1, h = 1
j = 1
N
Fix or (h>g) ?
Y
N
Fix or (j > N_T shr u) ?
Y
Inc (h)
N
T_D,i = (N_T shr (u -1))h - j +1 ?
Y
N
Fix ?
Y
T_C,i = T_C,i + (1 shl (N_D - v)), Fix = true
Inc (j)
Fix = Fix and (v < u shr 1), Inc (u), g = g shl 1
N
i < N ?
Y
Inc (i)
END

Below are some other features of the flow chart in Fig. 8. The comments concerning programming approach apply largely to the next flow chart in this manual as well:

- In order to speed up the computing, binary operations are used, given here in the Turbo Pascal® notation. Two of them may require an explanation:
  - *i* shl *j* shifts the value of *i* by *j* bits to the left;
  - *i* shr *j* shifts the value of *i* by *j* bits to the right.

- The conversion is only activated for joint types $T_{D,i} > 1$. Logical, because if $T_{D,i} = 1$ then $T_{C,i} = 1$. All entirely free joints (usually a majority in structure models) are in this way skipped, what fastens the procedure.

- The integer variables *i*, *u*, *v*, *g*, *h* and *j* are counters. Here are their ranges, in case the bit-level code presents some survey problems: *i*[1..*N*], *u*[1..2N_D], *v*[1..N_D], *g*[1..N_T] (binary i.e. 1, 2, 4, 8, etc.), *h*[1..*g*], *j*[1..$N_T/2^u$].

Fig. 8. Flow chart of DISCO unconditional conversion

- The counters *u* and *v* match discontinuous fixities (negative, positive or both) of joint DOF's with appropriate continuous ones. In simple terms: Each time *u* "spots" a fixity in a joint type number $T_{D,i}$, *v* increases the appropriate continuous type number $T_{C,i}$ by:
  $$2^{N_D - v} \quad \text{or binary:} \quad 1\,\text{shl}\,(N_D - v)\,.$$

- The counter *g* is actually a function of *u*:
  $$g = 2^{u-1} \quad \text{or binary:} \quad g = 1\,\text{shl}\,(u-1),$$
  and represents the column values in tables of discontinuous joint type numbers (see section 4).

- The counters *h* and *j* help *u* to find whether there is a fixity in these columns. This is the case when:
  $$T_{D,i} = \frac{N_T h}{2^{u-1}} - j + 1 \quad \text{or binary:} \quad T_{D,i} = (N_T\,\text{shr}\,(u-1)) * h - j + 1\,.$$

6.3 Conditional modification

Conditional modification is the most essential procedure of the algorithm. It modifies joint *i* fixities, i.e. the continuous type numbers $T_{C,i}$, to meet the discontinuous fixity conditions of that joint. In accordance with the strategy presented in section 4, the modification takes place in the two following cases:

1. When the *basic solution* produces a reaction $R_{i,v} \neq 0$ on a free side of a single-sided fixity in the DOF $v[1..N_D]$. That DOF becomes then modified from fixed in into free.
2. When the *basic solution* produces a displacement $D_{i,v} \neq 0$ on a fixed side of a single-sided fixity in the DOF $v[1..N_D]$. That DOF becomes then modified from free into fixed.

Since both cases involve testing of equalities to zero, there may arise numerical accuracy problems. The nature and the size of such problems depend on a number of factors, e.g.:
- complexity of structure models;
- presence of so-called ill-conditioned areas in these models;
- precision of floating point variables and operations, etc.

These problems are common in computer programming and do not need to be discussed here. DISCO makes use of two boundary 'considered-to-be-zero' values which proved to produce satisfactory results in PC-programming, assuming no very disproportional force or length units are used in the input data. These values[11)] are: $\varepsilon_1 = 10^{-6}$ and $\varepsilon_2 = 10^{-8}$.

ε_1 is used in zero-testing of both: displacements and reactions. The boundaries are:

$\lvert D_{i,v} \rvert < \varepsilon_1$	is considered to be:	$D_{i,v} = 0$;
$\lvert R_{i,v} \rvert < 1000\,\varepsilon_1$	is considered to be:	$R_{i,v} = 0$.

ε_2 is used to test numerical stability of the solution. When the solution is numerically stable, the products $D_{i,v}* R_{i,v}$ must equal 0. If this is not the case, the DOF *v* fixity of a particular joint *i* must not undergo modification in order to preserve convergence. The boundaries used in DISCO are:

$\lvert D_{i,v}* R_{i,v} \rvert < \varepsilon_2 \rightarrow$	DOF *v* of joint *i* stable, modification possible;
$\lvert D_{i,v}* R_{i,v} \rvert \geq \varepsilon_2 \rightarrow$	DOF *v* of joint *i* instable, no subject to modification.

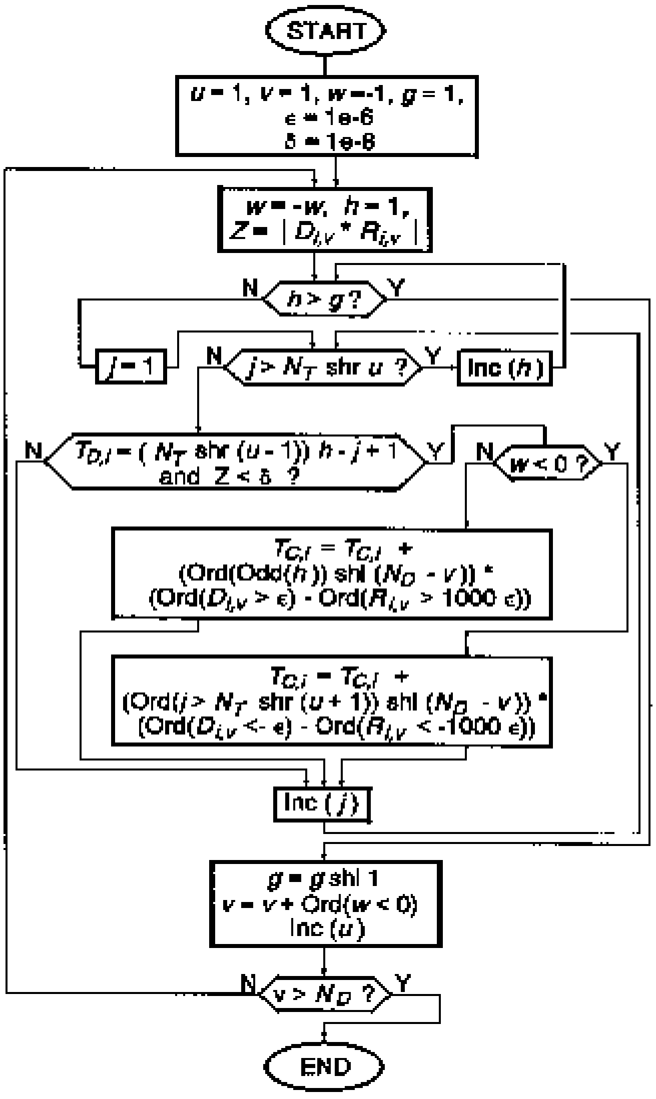
Fig. 9 presents a flow chart of the conditional modification, as programmed in DISCO. Here are some additional comments on this flow chart:

- In addition to the notation as discussed by flow charts in Fig. 7 and 8, the use of a logical Pascal function Ord(*expr.*) may require an explanation:
  - If the expression *expr.* making the argument of Ord is true, then Ord returns 1;
  - If the expression *expr.* is false, then Ord returns 0.

- Just as the unconditional conversion, the conditional modification becomes only activated for joint types $T_{C,i} > 1$. This speeds the computing considerably up.

- The integer variables *u*, *v*, *g*, *h* and *j* are counters; *w* is a sign switch. The ranges of these variables are as follows: $u[1..2N_D]$, $v[1..N_D]$, $g[1..N_T]$ (binary i.e. 1, 2, 4, 8, etc.), h[1..g], $j[1..N_T/2^u]$, w[-1,+1]. With the exception of *w*, the same notation is used here as in the flow chart of unconditional conversion.

11) In exceptional cases, these values may require to be tuned up. For more output stability, variable 'considered-to-be-zeros' can also be used, e.g. belonging to the input data or resulting from the analysis of numerical input. This has not been programmed but it may be considered in prosperous versions of DISCO.


START
u = 1, v = 1, w = -1, g = 1,
ε = 1e-6
δ = 1e-8
w = -w, h = 1,
Z = | D_{i,v} * R_{i,v} |
N
h > g ?
Y
j = 1
N
j > N_T shr u ?
Y
Inc (h)
N
T_{D,i} = (N_T shr (u - 1)) h - j + 1
and Z < δ ?
Y
N
w < 0 ?
Y
T_{C,i} = T_{C,i} +
(Ord(Odd(h)) shl (N_D - v)) *
(Ord(D_{i,v} > ε) - Ord(R_{i,v} > 1000 ε))
T_{C,i} = T_{C,i} +
(Ord(j > N_T shr (u + 1)) shl (N_D - v)) *
(Ord(D_{i,v} < - ε) - Ord(R_{i,v} < -1000 ε))
Inc (j)
g = g shl 1
v = v + Ord(w < 0)
Inc (u)
N
v > N_D ?
Y
END

- Fixity detection in the columns of joint type definition (see examples in section 5) takes place in the same way as in unconditional conversion. The initial model contains a fixity in a column *u* if:

$$T_{D,i} = \frac{N_T h}{2^{u-1}} - j + 1, \quad \text{or binary:}$$

$$T_{D,i} = (N_T \,\text{shr}\, (u-1)) * h - j + 1 .$$

- If the computed displacement and reaction show no numerical instability, i.e. if one of the two can be considered 0, the appropriate DOF *v* fixity may undergo modification.

- The algorithm checks first positive, and then negative side of DOF *v*. The switch is controlled by a sign switch *w*. The check and the modification take place in one operation, thanks to the use of a logical function Ord(*expr.*), see the two main blocks middle in the flow chart. The upper block is activated when there is a fixity on the positive side of DOF *v*; the lower block - when the negative side of DOF *v* is fixed.

Fig. 9. Flow chart of DISCO conditional modification

- Observe that the entire procedure is ruled by the output of current iteration steps. The continuous joint type numbers $T_{C,i}$ become increased, respectively decreased, without checking up if they do not already contain the fixity or the freedom of DOF *v*. Such programming can only be successful if all possible output combinations are controlled, including numerical instabilities. This is indeed the strategy in DISCO.

- Both main operation blocks contain an exit option for numerical instabilities. These are not the same form of instabilities as the one handled by the condition $|D_{i,v} * R_{i,v}| < \varepsilon_2$. Basically, two forms of numerical instability can be distinguished in the program:
  - Inaccuracy problems: Caused usually by too complex modeling and relatively low variable and/or operation precision. To recognize, e.g., by unstable zero's in the output. This form is primarily handled by the ε_1-conditions.
  - Out of range problems: Caused usually by so-called ill-conditioned features. To recognize by the output of high real numbers, usually a number of ranges higher than the input values. This form is primarily handled by the ε_2-condition.

- The modification results in fixing or releasing the DOF *v*, depending on the computed displacement $D_{i,v}$ and reaction $R_{i,v}$. If the use of the Ord-function presents some survey inconveniences, a simpler notation in Table 4 can be helpful:

Table 4. Action of two main operation blocks in Fig. 8

The upper block:

	$R_{i,v} \le 1000\ \varepsilon_1$	$R_{i,v} > 1000\ \varepsilon_1$
$D_{i,v} \le \varepsilon_1$	Positive side loaded, correct. No change.	Releasing *v*. $T_{C,i}$ decreases by $2^{N_D - v}$
$D_{i,v} > \varepsilon_1$	Fixing *v*. $T_{C,i}$ increases by $2^{N_D - v}$	Numerical instability, exit. No change.

The lower block:

	$R_{i,v} \ge -1000\ \varepsilon_1$	$R_{i,v} < -1000\ \varepsilon_1$
$D_{i,v} \ge -\varepsilon_1$	Negative side loaded, correct. No change.	Releasing *v*. $T_{C,i}$ decreases by $2^{N_D - v}$
$D_{i,v} < -\varepsilon_1$	Fixing *v*. $T_{C,i}$ increases by $2^{N_D - v}$	Numerical instability, exit. No change.

- There is one more special case covered by the ε-conditions. It arises when both: displacement $D_{i,v}$ and reaction $R_{i,v}$ are equal to 0, i.e. when DOF *v* of joint *i* is not effected by load in any sense. It can appear e.g. when there is another sufficiently fixed joint between *i* and the load, when the entire system is not loaded in direction *v*, or when the strains in this direction are in internal equilibrium in the vicinity of *i*. Also in such case no fixity modification is performed.

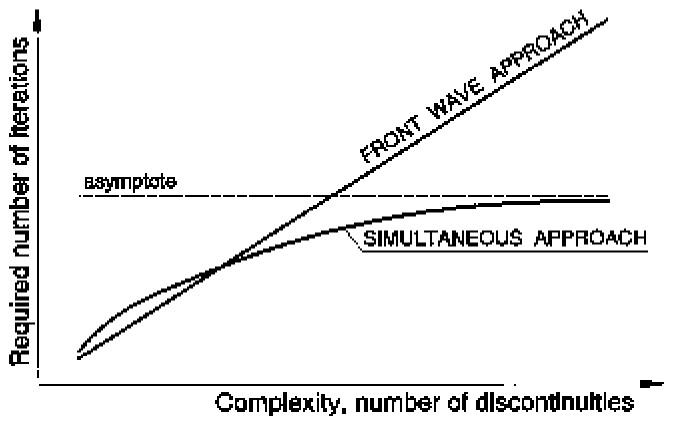
7. POSSIBLE EXTENSIONS OF THE ALGORITHM

In the form presented in this manual, the DISCO algorithm proved to give sufficient support in numerous polygonally linear (discontinuous) problems in the recent 16 years of the author's engineering practice. Nevertheless, there are problems which can possibly be better approached in another way, or which might require some extensions to the algorithm. A good reason to consider such extensions is that the algorithm proves to be relatively high performing.

One of the sources of this performance - use of the fast, binary arithmetic - has already been discussed. Another one is a *simultaneous approach* strategy - analyzing the whole set of system discontinuities at a time. The practice shows that the number of iteration steps does not grow with the number of discontinuities (with exception of some trivial cases as the beam in section 4), but usually becomes stabilized at a certain level. This is a very favorable feature. An algorithm using a kind of *successive approach*, i.e. solving the discontinuities successively, would require more iteration steps for complex discontinuous systems[12]. This difference is visualized in Fig. 10.

Another source of high performance is the stability of solutions. Note that the entire iteration process is ruled by logical algebra; no numerical values are passed from one iteration step to the next one. In consequence, there is no danger of error accumulation. This advantage will not be found in diverse nonlinear programs which are often used to approximate discontinuous behavior.

[12] This comparison has not been studied further but a certain analogy can be drawn to the performance of iterative (Jacobi, Gauss-Seidler [14], [15]) and direct (Gauss) solutions of simultaneous equation systems. The first ones perform better by large, complex systems.



Below is a brief discussion on extension- and modification ideas which can still be considered. These ideas have not yet been tested in a computer program. The discussion is therefore somewhat speculative. Nevertheless, it might be helpful to prospective programmers:

Fig. 10. Number of iterations in two strategies of the analysis

- Extension for internal discontinuities:

Member begin- and end joints can be given joint type numbers in the similar way as for the external discontinuities. Then the two programming strategies can be considered:

1. Expanding *unconditional conversion* and *conditional modification* in such a way that all (internal and external) fixities are handled at a time. This leads to a single level iteration, probably the fastest. Additional convergence precautions may then be needed.
2. Dividing the procedure: Each step of 'external' fixity iteration contains then an entire 'internal' fixity iteration. Such a double level iteration is probably slower but better convergent.

Naturally, in internal fixity modifications the global joint displacements should be used as boundary values, not zeros. This presents some problems since these displacements may as well be effected by discontinuously connected members. The iteration will probably require a deeper joint analysis then presented in this manual[13].

- Discontinuous edge- or surface supports:

In order to simulate a linear or surface discontinuous support, the user has to input a large number of pointed discontinuities. This can, obviously, be avoided by defining special contact interfaces, modules etc., allowing to input entire contact edges or surfaces as single items. Such procedures are known e.g. to generate complex finite element types[14], and do not need to be discussed here. This extension seems to be convenient for large FEM programs, running on networks with powerful central units. DISCO has been programmed for a small stand alone PC with a limited operation memory (the used Turbo Pascal version can not address more than 64 kB), therefore it made little sense to extend it in that way.

- Mutually related discontinuities:

In section 4, four fixity conditions of a discontinuous DOF are distinguished. This covers most forthcoming problems. There are cases, however, where fixity of a single DOF depends on a fixity of another DOF rather than on a sign of displacement in the same DOF. In the sample problem presented further in this manual, it would probably be more convenient to relate the fixity of rotation angle A_Z to the fixity of displacement D_X. Such relations can be realized e.g. by adding another joint type number - this time for mutually related discontinuities - to the current one; and expanding the *conditional modification*. For mutually related discontinuities the type numbers > T_D can possibly be used. Since such discontinuities are seldom, a proper detection could be performed prior to entering the expanded routines.

[13] A quite deep analysis, based however on a different, incremental search algorithm, has been presented in [22].

[14] Special types of complex elements, which are in fact used nowadays to simulate contact problems, are boundary elements [23]. In particular the hybrid methods combining finite- and boundary element approach [24], [25] have been successful in this field.

- Other than zero discontinuity levels:

As already mentioned, it is a minor problem to install other than zero discontinuity levels. Instead of (or next to) detecting positive and negative displacements and reactions, the algorithm would distinguish between the values below and above certain levels, which should then be specified in the input data. Also this possibility will not be used often in structural engineering, but it can be helpful e.g. in simulations of plastic hinges, supports on buoyancy tanks etc. It can not be used for modeling fracture problems (e.g. cracks), as the algorithm handles only polygonal behavior, where there is just one function value for each argument. In fracture problems more values are possible for a single argument.

- Fracture discontinuities:

The above does not necessarily mean that no routines of the algorithm can be adapted in fractural discontinuity analyses. Especially interesting for this purpose can be:

1. The binary technique of coding joint types (the number of types might be larger);
2. The so-called stiff approach (see section 4) and the unconditional conversion;
3. Conditional modification in an internal iteration within a load step.

In general, it looks promising to use the discussed routines within the user defined load steps in fracture analyses. As the algorithm does not contribute to error accumulation, this will probably lead to ‘fine tuning’ of load step results. The error accumulation effect can in this way be limited to inaccuracies at transition points between the load steps.

- Non-linear polygonal problems:

In non-linear polygonal analyses (see discussion on terminology at the beginning of this paper) a strategy opposite to the one mentioned above seems more promising: Use the non-linear routines within the algorithm iteration steps. Such approach would possibly lead to a very accurate, multi-purpose structural analysis programming. However, the following two problems should be taken into consideration:

1. The non-linear procedures must then be highly accurate as well. Their error should in principle not exceed the boundaries set by the ε-conditions, see section 6.3.
2. In case of large displacements, some extra precautions may be necessary to ensure convergence. Convergence problems are, however, not new in non-linear analysis.

CONTENTS

8. DELIVERY CONDITIONS, HARDWARE REQUIREMENTS

DISCO has been developed by the author with no contribution of any third parties of persons. The author does not intend to register this software or to take any other steps to protect his rights and/or distribute his product commercially. As this software has been enclosed to the doctor's thesis submitted at the Civil and Environmental Engineering Department of the Gdansk University of Technology (further called ”the University”), the University owns now its copy rights. As such, the University may take steps to protect these right, and/or impose any distribution or other restrictions according to its policy.

Although utmost care was taken to debug this software, nor the author neither the University can be held responsible for any consequences of its applications. In particular, users are warned that unprofessional modifications of the included Pascal and text files (e.g. intended to adapt third party lay-outs) may cause the damage of the software.

The software is delivered in a set containing:

- this manual;
- one 3½” diskette named ‘DISCO’ and containing:
  - system files in directories DISCO and DANCE;
  - data files in directories CBE, DBE, CPT, DPT, CGR, DGR, CPF, DPF, CST, DST, CSF, DSF.

As the first software versions were developed in the late 1980's, the hardware requirements are quite mild in relation to the current standards. What the user needs, is only:

- PC running under any version of MS Windows or MS DOS;
- hard disk in drive C:\ with about 1 MB memory space for the DISCO system files;
- graphical card “on board” enabling the emulation of one of the following cards: CGA, MCGA, EGA,VGA or Hercules;
- diskette drive, USB port or any other data storage device – as long as it is configured to be A:\.

The delivered software version can not address a data storage port other than A:\. It is also not tailored for running in a network system, although it can be adapted to that by a skilled professional.

9. PROGRAM INSTALLATION

To install the DISCO software on your PC, please do the following:

1. Make a back-up copy of your original DISCO diskette.
2. Take a new diskette, a USB memory key or any other data storage medium assigned to drive A:\, and copy all data file directories (CBE through DSF) into it. Label it, e.g., “DISCO data”[15).

For operation under MS Windows:

3. Insert your DISCO diskette into a disk drive of your PC. Get its directory on the screen.
4. Use MS Windows Explorer to copy the entire directories (names and contents) DISCO and DANCE into drive C:\ (Attention: Not into C:\Programs or any other directory on drive C:\).
5. Click on C:\DISCO and get its directory on the screen.
6. Link (shortcut) the DISCO.EXE file to your MS Windows desktop
   (Attention: Not the DISCO files with other extensions, e.g. PAS, BAK).
7. Link (shortcut) the DANCE.BAT file (MS DOS batch file) to your MS Windows desktop
   (Attention: Not the DANCE files with other extensions, e.g. EXE, PAS, BAK, TXT).
8. Get your desktop screen, insert the DISCO data disk in drive A:\, click on DISCO and … Voila!

15) Further in this manual, we shall talk about “data disk” and “drive A:\” only. However, it refers also to, e.g., “USB data key ” and “port A:\” if this is the configuration of your computer.

For operation under MS DOS:

3. Insert your DISCO diskette into a disk drive of your PC. Get the prompt C:\.
4. Copy the entire directories (names and contents) DISCO and DANCE into drive C:\, e.g. using the DOS Xcopy /s command (Attention: Not into any other directory on drive C:\).
5. Log into the DISCO directory , e.g. by typing CD \DISCO and pressing <Enter>.
6. Insert the DISCO data disk in drive A:\, type DISCO, press <Enter> and … Voila!

Your DISCO system is operational now and you can – in principle – start processing the example data files on your data disk and computing their solutions You can also input and compute your own data files. It is advisable, however, to read the rest of this manual first. In particular, deleting the supplied data files or modifying them through the DISCO dialogue may result in a loss of valuable examples.

10. STRUCTURE MODELING

10.1. General assumptions

As discussed in section 5, DISCO performs structural analyses for structure models of twelve different types. Therefore, you should first choose the type which suits your problem the best. Keep in mind that the higher your structure type number will be, the more complex and memory consuming computation it will require. In extreme cases, i.e. by very large space frame models, the program may even run out of memory. Special program architecture and the use of a band matrix optimization take care that this does not happen soon. Exact limits can not be given, but space frames up to about 150 nodes (joints) and 200 members should, in general, successfully be computed. For other types of structures, these limits usually exceed 800. The only programmed limitation is no more than 999 joints and 999 members.

There are six basic types of structures to be chosen from (Fig. 11), divided into two groups as follows:

1 Continuous beam;	**2** Discontinuous beam;
3 Continuous plane truss;	**4** Discontinuous plane truss;
5 Continuous grid;	**6** Discontinuous grid;
7 Continuous plane frame;	**8** Discontinuous plane frame;
9 Continuous space truss;	**10** Discontinuous space truss;
11 Continuous space frame;	**12** Discontinuous space frame.

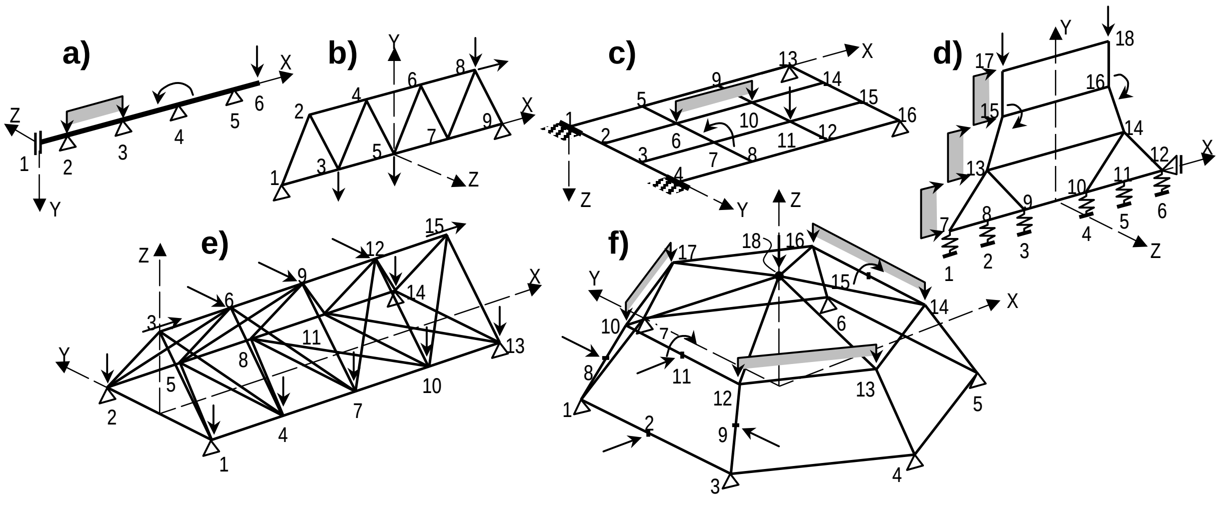


Fig. 11. Six basic types of structures – examples

The structure geometry must be input in a global right-handed (Cartesian) coordinate system. For the types **1** ÷ **8** (**a** ÷ **d** in Fig 11), the position of the global coordinate axes is partly predefined by assuming that the structure must lie in the global XY plane. For beams, types **1** and **2** (**a** in Fig. 11), the additional assumptions are that the global X axis coincides with the beam, the loads act in the global XY plane, and the joints and members are sequentially numbered in the positive direction of X. For the types **9** ÷ **12** (**e** and **f** in Fig. 11), any position of the global coordinate system can be chosen.

The difference between continuous and discontinuous structures has been discussed in section 1 of this manual. The terms "beam", "plane truss", "grid", "plane frame", "space truss" and "space frame" are widely known. To avoid confusion, however, here is how DISCO sees these types of structures:

a) Beams

Beams are linear, straight structures, supported by any number of pointed supports fixing any degree of freedom (DOF) or a combination of DOF's. The DOF's of a beam node (joint) are deflection D_y and rotation angle A_z . Beams can be loaded by pointed forces F_y and moments M_z , as well as by member (in DISCO equally) distributed loads q_y . Beam members can have different sectional rigidity EI_z , which is the only parameter determining their flexural behavior.

b) Plane trusses

Plane trusses are 2D structures built of linear, straight members with all joints (also supports) hinged. The DOF's of a plane truss joint are displacements D_x and D_y . Any number of DOF fixities (supports) or their combinations is possible. Plane trusses can only bear pointed loads in joints. These loads are force components F_x and F_y . Truss members can have different sectional rigidity EA_x , which is the only parameter determining the truss deformation.

c) Grids

Grids are 2D structures built of linear, straight members with rigid internal joints; and loaded perpendicularly to the structure plane. The DOF's of a grid joint are displacement D_z and rotation angles A_x and A_y . Grids can be supported by any number of joint DOF fixities or their combinations. The possible grid loads are joint force F_z , joint moments M_x and M_y , and member (in DISCO equally) distributed load q_z . Grid members have two sectional rigidities: torsional GI_x and flexural EI_y .

d) Plane frames

Plane frames are 2D structures built of linear, straight members with rigid internal joints; and loaded in the structure plane. The DOF's of a plane frame joint are displacements D_x and D_y and a rotation angle A_z . Also plane frames can be supported by any number of joint DOF fixities or their combinations. The possible loads are joint forces F_x and F_y , joint moment M_z , and member (in DISCO equally) distributed loads q_x and q_y . Plane frame members have two sectional rigidities: axial EA_x and flexural EI_z .

e) Space trusses

Space trusses are 3D structures built of linear, straight members with all joints (also supports) hinged. The DOF's of a space truss joint are displacements D_x , D_y and D_z . Any number of DOF fixities (supports) or their combinations is possible. Space trusses can only bear pointed loads in joints. These loads are force components F_x , F_y and F_z . Truss members can have different sectional rigidity EA_x , which is the only parameter determining the truss deformation.

f) Plane frames

Space frames are 3D structures built of linear straight members with rigid internal joints. The DOF's of a space frame joint are displacements D_x , D_y and D_z , and rotation angles A_x , A_y and A_z . Space frames can be supported in any number of joint DOF fixities or their combinations. The possible loads are joint forces F_x , F_y and F_z , joint moments M_x , M_y and M_z, and member equally distributed loads q_x , q_y and q_y . Space frame members have four sectional rigidities: axial EA_x, torsional GI_x and two flexural EI_y and EI_z.

10.2. Global and local coordinates

As mentioned in section 10.1, DISCO makes use of a right-handed, orthogonal (Cartesian) coordinate system. This system, including the positive sign convention, is shown below (Fig. 12). In can be convenient to memorize the positive rotation signs as clockwise when looking in the positive direction of proper axes. Memorizing the mutual position of the system axes is essential. Swapping two of them will produce a left-handed system which requires another interpretation than the one presented in this manual. The program uses the system from Fig. 12 in two different manners:

- as a global coordinate system;
- as a local coordinate system.

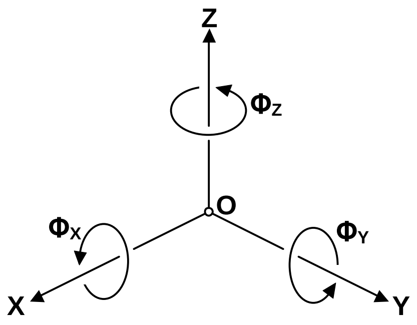


Fig. 12. Right-handed orthogonal coordinate system

Global coordinate system is the system as allocated by the user, within the assumptions discussed in section 10.1. As the name says, that system shall be used for all input data and solution results that are globally orientated, i.e. refer to the entire model rather than a particular member. In particular, the following data must be input in the global coordinate system:

- joint fixities (types);
- joint coordinates;
- joint loads;
- member distributed loads.

The program will return the following solution results in the global coordinate system:

- joint displacements;
- support reactions.

Local coordinate system is a system associated with a particular member of the structure. Unlike the global system, the position of the local system is defined by the program, nor by the user. Its origin lies always in the beginning of the member; and the local x axis always coincides with the member itself, pointing at the end of it (Fig. 13).

For beams, the local system is further identical to the global one, when moved parallel to the beginning of the member.

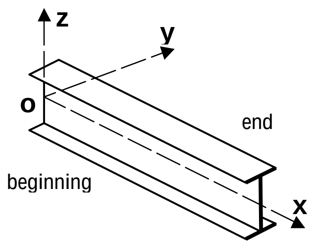


Fig. 13. Member local coordinate system

For plane trusses, grids and plane frames, the local system may also rotate about the z-axis in order to let the x-axis match the direction of the member. The local y-axis follows this rotation and the local z-axis remains parallel to the global Z-axis. In trusses (also space trusses), you may forget the local axes y and z, since truss members can only bear loads in the x-direction. The members of plane frames can also bear shear in the y-direction and bending moments about the z-axis.

In space frames, the local axes y and z are defined as follows:

- The y-axis is parallel to the global XY-plane. In vertical members it is directed the same as the global Y-axis.
- The z-axis lies in a vertical plane containing the x-axis. Its projection on the global Z-axis is never negative.

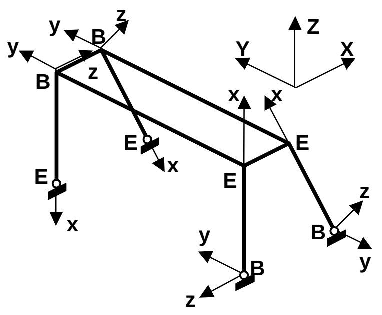


Fig. 14. Local system in the posts of a football goal

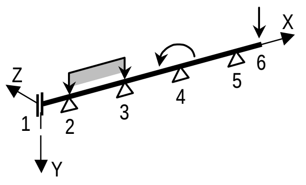
This definition applies when the global Z-axis is vertical, which is an advised choice. A good example of it is the determination of local axes in the posts of a football goal, see Fig. 14. If the global Z-axis is not vertical, than “vertical members” should be read as members perpendicular to the global XY-plane; and “vertical plane” should be read as plane parallel to the global Z-axis.

10.3. Coding discontinuous fixities

As discussed in section 5, each joint of your structure has a joint type number that defines its external fixities. It must explicitly be included into your input data. The method to determine joint type numbers has globally been shown, using the most complex case – a space frame joint – as an example. Following are the table headlines for joint type determination in all 12 types of structures that can be computed by DISCO, along with some calculation examples (Tables 5):

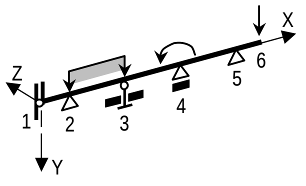
Table 5. Joint type determination in 12 types of structures

- Continuous beam:



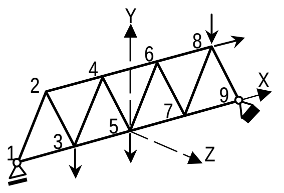
Joint no.	D_Y 2^1	A_Z 2^0		Type no.
1	/	#	+1=	2
2	#	/	+1=	3
6	/	/	+1=	1

- Discontinuous beam:



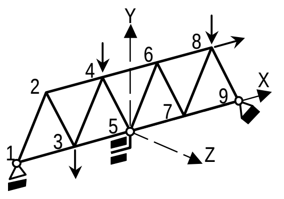
Joint no.	- D_Y +		- A_Z +			Type no.
	2^3	2^2	2^1	2^0		
1	#	#	#	/	+1=	15
3	#	/	/	/	+1=	9
4	/	#	/	/	+1=	5

- Continuous plane truss:



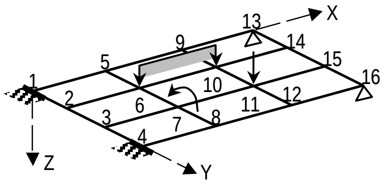
Joint no.	D_X 2^1	D_Y 2^0		Type no.
1	/	#	+1=	2
5	/	/	+1=	1
9	#	#	+1=	4

- Discontinuous plane truss:



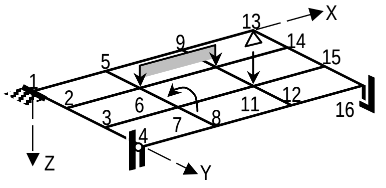
Joint no.	- D_X +		- D_Y +			Type no.
	2^3	2^2	2^1	2^0		
1	/	/	#	/	+1=	3
5	#	/	#	#	+1=	12
9	#	#	#	#	+1=	16

- Continuous grid:



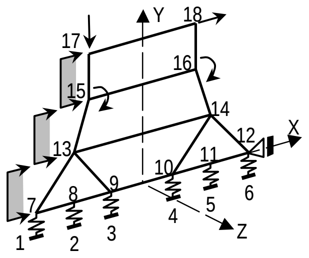
Joint no.	D_Z 2^2	A_X 2^1	A_Y 2^0		Type no.
1	#	#	#	+1=	8
7	/	/	/	+1=	1
13	#	/	/	+1=	5

- Discontinuous grid:



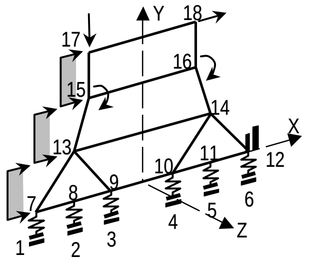
Joint	- D_Z +		- A_X +		- A_Y +			Type
no.	2^5	2^4	2^3	2^2	2^1	2^0		no.
1	#	#	#	#	#	#	+1=	64
4	/	#	/	/	#	/	+1=	19
16	/	#	#	/	/	/	+1=	25

- Continuous plane frame:



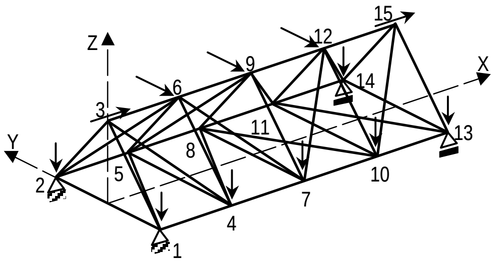
Joint no.	D_X 2^2	D_Y 2^1	A_Z 2^0		Type no.
1	/	#	#	+1=	4
9	/	/	/	+1=	1
12	#	/	/	+1=	5

- Discontinuous plane frame:



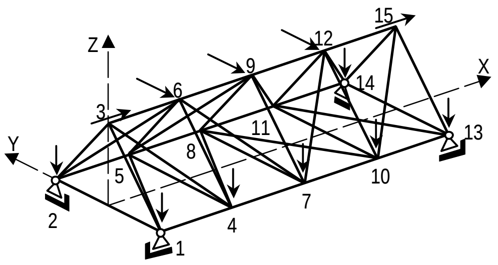
Joint	- D_X +		- D_Y +		- A_Z +			Type
no.	2^5	2^4	2^3	2^2	2^1	2^0		no.
1	/	/	#	/	#	#	+1=	12
9	/	/	/	/	/	/	+1=	1
12	/	#	/	/	#	/	+1=	19

- Continuous space truss:



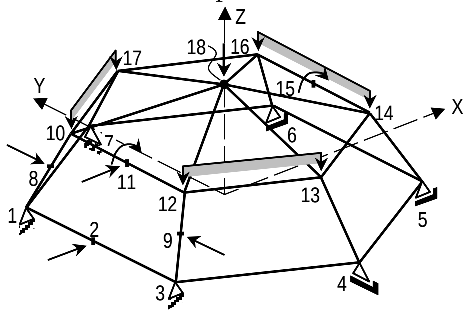
Joint no.	D_X 2^2	D_Y 2^1	D_Z 2^0		Type no.
1	#	#	#	+1=	8
2	#	/	#	+1=	6
13	/	#	#	+1=	4

- Discontinuous space truss:



Joint	- D_X +		- D_Y +		- D_Z +			Type
no.	2^5	2^4	2^3	2^2	2^1	2^0		no.
1	#	/	/	/	#	/	+1=	35
2	/	/	#	/	#	/	+1=	11
13	/	#	#	#	#	/	+1=	31

- Continuous space frame:



Joint	D_X	D_Y	D_Z	A_X	A_Y	A_Z		Type
no.	2^5	2^4	2^3	2^2	2^1	2^0		no.
3	#	#	#	/	/	/	+1=	57
4	/	#	#	/	/	/	+1=	25
5	#	/	#	/	/	/	+1=	41

- Discontinuous space frame:

Joint	- D_X +		- D_Y +		- D_Z +		- A_X +		- A_Y +		- A_Z +			Type
no.	2^{11}	2^{10}	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0		no.
3	#	#	#	#	#	#	/	/	/	/	/	/	+1=	4033
4	/	/	#	/	#	/	/	/	/	/	/	/	+1=	641
5	/	#	/	/	#	/	/	/	/	/	/	/	+1=	1153

11. INPUT OF DATA

11.1. Data format - general

Your data must be submitted in a text file (a file with extension .TXT), stored in drive A:\ on a diskette or other data storage medium in one of the following directories:

\CBE	for	Continuous beams;	**\DBE**	for	Discontinuous beams;
\CPT	for	Continuous plane trusses;	**\DPT**	for	Discontinuous plane trusses;
\CGR	for	Continuous grids;	**\DGR**	for	Discontinuous grids;
\CPF	for	Continuous plane frames;	**\DPF**	for	Discontinuous plane frames;
\CST	for	Continuous space trusses;	**\DST**	for	Discontinuous space trusses;
\CSF	for	Continuous space frames;	**\DSF**	for	Discontinuous space frames.

The data file names have the same names as the names of the directories, followed by a sequential number from the range [1..99]. E.g., the full address of the first discontinuous grid data file will always be: A:\DGR\DGR1.TXT

The data file consists of three parts that **must** be submitted, followed by one part that **may** be submitted in case you like additional details on the behavior of some members. All these parts must be separated from each other by a single free line. The data file parts are:

- **General data:**
  project and/or structure name, force and length units, total numbers of joints and members[16].
- **Joint data:**
  per input line: joint type, joint global coordinates, joint concentrated loads.
- **Member data:**
  per input line: beginning and end joint[16], sectional rigidities, member distributed loads.
- **Members for extended output:**
  member numbers of for detailed output of extreme deflections and bending moments.

Observe that this data combines the data about structure geometry and stiffness with the data about structure loads. The latter not only do not make a separate 'loading file', but they are even given in the same input lines as the first. This would be surprising in computer programs performing a conventional, "continuous" analysis, but is a logical and deliberate step in DISCO. In discontinuous analyses, superposition of different loading cases is – by definition – an error, because loadings co-define the systems, see discussion in section 3. Therefore, no provisions should be made to encourage such a superposition.

11.2. Input in a text file

The data file can be prepared in two different manners:
- Using a text editor which can process the *.TXT files;
- Using the DISCO own interactive input dialogue.

The first way is faster and offers better review possibilities for a skilled program user. It may, however be less convenient for a beginner. As the only test of the data is then the program run itself, it may cost a number of runs before the data file is debugged. The second way is slower and offers less review possibilities, but it makes it almost impossible to produce a file resulting in a runtime error. That way will be discussed in the following section.

There are a number of text editors which can process *.TXT files. All computers working under the MS Windows operating system are, e.g., standard supplied with a WordPad editor. This editor produces and processes the *.TXT files. Such files are also produced by a range of old text editors running under the MS DOS operating system. Also the compilers of popular high-level computer languages contain editors of such files. The author, e.g., wrote his first data files in the editor of Borland's Turbo Pascal®, the same compiler that was used to develop and test the actual program.

Let us assign:

Project	=	name of the project, loading case etc.	– string up to 56 characters;
Fu	=	force units, e.g.: kN, N, T, kG, Lb	– string up to 2 characters;
Lu	=	length units, e.g.: m, cm, mm, ft, in	– string up to 2 characters;
n	=	number of joints	– positive integer < 999;
m	=	number of members	– positive integer < 999;
i	=	sequential joint number	– positive integer < n;
j	=	sequential member number	– positive integer < m;
T_i	=	type number of joint I	– positive integer, see section 10.3;
X, Y, Z	=	global coordinates X, Y and Z	– real values in *Lu*;
x, y, z	=	local coordinates x, y and z	– real values in *Lu*;
l_j	=	length of member j	– positive real value in *Lu*;

[16] The number of members is superfluous for beams. In beams, this number equals the number of joints, minus one. The member beginning and end joints are also superfluous there, as the joints are numbered sequentially.

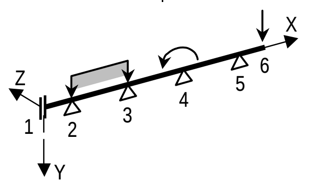
F_{Xi}, F_{Yi}, F_{Zi}	=	joint *i* concentrated force loads in global axes	– real values in *Fu*;
M_{Xi}, M_{Yi}, M_{Zi}	=	joint *i* concentrated moment loads about global axes	– real values in *Fu·Lu*;
b_j , e_j	=	beginning and end joint of member *j*	– positive integer < *n*;
$EA_{x,j}$	=	section axial rigidity of member *j*	– positive real value in *Fu*;
$GI_{x,j}$	=	section torsion rigidity of member *j*	– positive real value in $Fu{\cdot}Lu^2$;
$EI_{y,j}$	=	section bending rigidity of member *j* about the local y-axis	– positive real value in $Fu{\cdot}Lu^2$;
$EI_{z,j}$	=	section bending rigidity of member *j* about the local z-axis	– positive real value in $Fu{\cdot}Lu^2$;
q_{Xj}, q_{Yj}, q_{Zj}	=	member *j* distributed loads in global axes	– real values in *Fu/Lu*;

With the exception of the data *Project* that occupies a whole input, all other data have to be sorted out in lines and separated from each other by one or more blanks (no commas!). Below (Tables 6 ÷ 10) are the data formats for the six types of structures from section 10.1. The only difference between continuous and discontinuous data files (not mentioning their names) is that the continuous joint types T_{Ci} change into the discontinuous ones T_{Di} , as shown in section 10.3. The data in brackets [...] are optional. If you, e.g., only want to enter the second of them, you must – obviously – enter a zero for the first.

Table 6. Format of data files for beams and plane trusses

Beams (files CBE*.TXT and DBE*.TXT):	
General	**Example**
Project	`Beam - Figure 11a`
Fu Lu n	`kN m 6`
free line	
T_1 X_1 [F_{Y1} M_{Z1}]	`2  0`
T_2 X_2 [F_{Y2} M_{Z2}]	`3  2`
……	`3  6`
T_i X_i [F_{Yi} M_{Zi}]	`3 10   0  15`
……	`3 14`
T_n X_n [F_{Yn} M_{Zn}]	`1 16 -10`
free line	
EI_{z1} [q_{y1}]	`2E4`
EI_{z2} [q_{y2}]	`2E4 -4`
……	`2E4`
EI_{zj} [q_{yj}]	`2E4`
……	`2E4`
EI_{zm} [q_{ym}]	
free line	
[j_1 j_2 j_3 j_4 ...]	`2 3 4`

Plane trusses (files CBE*.TXT and DBE*.TXT):	
General	**Example**
Project	`Truss - Figure 11b`
Fu Lu n m	`kN m 9 15`
free line	
T_1 X_1 Y_1 [F_{X1} F_{Y1}]	`2  0.0 0.0`
T_2 X_2 Y_2 [F_{X2} F_{Y2}]	`1  3.0 5.0`
……	`1  6.0 0.0    0 -100`
T_i Xi Yi [F_{Xi} F_{Yi}]	`1  9.0 5.0`
……	`1 12.0 0.0    0 -100`
	`1 15.0 5.0`
	`1 18.0 0.0`
	`1 21.0 5.0   50  -50`
T_n X_n Y_n [F_{Xn} F_{Yn}]	`4 24.0 0.0`
free line	
b_1 e_1 EA_{x1}	`1  3 1E6`
b_2 e_2 EA_{x2}	`3  5 1E6`
……	`5  7 1E6`
b_j e_j EA_{xj}	`7  9 1E6`
……	`2  4 1E6`
b_m e_m EA_{xm}	`4  6 1E6`
	`6  8 1E6`
	`1  2 5E5`
	`2  3 2E5`
	`3  4 2E5`
	`4  5 2E5`
	`5  6 2E5`
	`6  7 2E5`
	`7  8 2E5`
	`8  9 5E5`



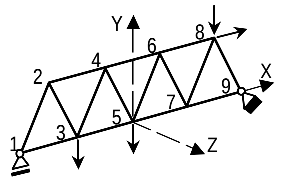


Table 7. Format of data files for grids

Grids (files CGR*.TXT and DGR*.TXT):

General

Project
Fu Lu n m
free line
T_1 X_1 Y_1 $[F_{Z1}$ M_{X1} $M_{Y1}]$
T_2 X_2 Y_2 $[F_{Z2}$ M_{X2} $M_{Y2}]$
……
T_i Xi Yi $[F_{Zi}$ M_{Xi} $M_{Yi}]$
……
T_n X_n Y_n $[F_{Zn}$ M_{Xn} $M_{Yn}]$
free line
b_1 e_1 GI_{x1} EI_{y1} $[q_{z1}]$
b_2 e_2 GI_{x2} EI_{y2} $[q_{z2}]$
……
b_j e_j GI_{xj} EI_{yj} $[q_{zj}]$
……
b_m e_m GI_{xm} EI_{ym} $[q_{zj}]$
free line
$[j_1$ j_2 j_3 $j_4 \ldots]$

Example

```
Grid - Figure 11c
kN m 16 24

8  0  0
1  0  3
1  0  6
8  0  9
1  5  0
1  5  3
1  5  6   0 -50
1  5  9
1 10  0
1 10  3
1 10  6  75
1 10  9
5 15  0
1 15  3
1 15  6
5 15  9

 1  2 2E4 4E5
 2  3 2E4 4E5
 3  4 2E4 4E5
 5  6 2E4 4E5
 6  7 2E4 4E5
 7  8 2E4 4E5
 9 10 2E4 4E5
10 11 2E4 4E5
11 12 2E4 4E5
13 14 2E4 4E5
14 15 2E4 4E5
15 16 2E4 4E5
 1  5 5E4 1E6
 2  6 5E4 1E6
 3  7 5E4 1E6
 4  8 5E4 1E6
 5  9 5E4 1E6
 6 10 5E4 1E6  20
 7 11 5E4 1E6
 8 12 5E4 1E6
 9 13 5E4 1E6
10 14 5E4 1E6
11 15 5E4 1E6
12 16 5E4 1E6
```

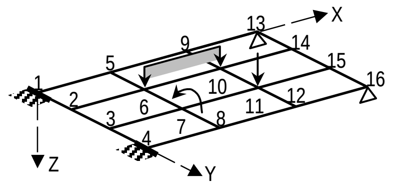


Table 8. Format of data files for plane frames

Plane frames (files CPF*.TXT and DPF*.TXT):

General

Project
Fu Lu n m
free line

Example

```
Plane frame - Figure 11d
kN m 18 22
```

Continued on the next page…

Table 8 continued:

T_1 X_1 Y_1 [F_{X1} F_{Y1} M_{Z1}]	4 -6.0 -0.2
	4 -4.0 -0.2
T_2 X_2 Y_2 [F_{X2} F_{Y2} M_{Z2}]	4 -2.0 -0.2
……	4 2.0 -0.2
T_i Xi Yi [F_{Xi} F_{Yi} M_{Zi}]	4 4.0 -0.2
	4 6.0 -0.2
……	1 -6.0 0.0
T_n X_n Y_n [F_{Xn} F_{Xn} M_{Zn}]	1 -4.0 0.0
free line	1 -2.0 0.0
b_1 e_1 EA_{x1} EI_{z1} [q_{X1} q_{Y1}]	1 2.0 0.0
	1 4.0 0.0
b_2 e_2 EA_{x2} EI_{z2} [q_{X2} q_{Y2}]	5 6.0 0.0
……	1 -4.0 3.0
b_j e_j EA_{xj} EI_{zj} [q_{Xj} q_{Yj}]	1 4.0 3.0
	1 -3.0 6.0 0 0 -50
……	1 3.0 6.0 0 0 -50
b_m e_m EA_{xm} EI_{zm} [q_{Xm} q_{Zm}]	1 -3.0 9.0 0 -75
free line	1 3.0 9.0 20
[j_1 j_2 j_3 j_4 …]	
	1 7 2.0E3 1.0
	2 8 2.0E3 1.0
	3 9 2.0E3 1.0
	4 10 2.0E3 1.0
	5 11 2.0E3 1.0
	6 12 2.0E3 1.0
	7 8 8.0E5 6.0E4
	8 9 8.0E5 6.0E4
	9 10 8.0E5 6.0E4
	10 11 8.0E5 6.0E4
	11 12 8.0E5 6.0E4
	7 13 2.0E5 5.0E3 16.0
	13 15 2.0E5 5.0E3 18.0
	15 17 2.0E5 5.0E3 20.0
	12 14 2.0E5 5.0E3
	14 16 2.0E5 5.0E3
	16 18 2.0E5 5.0E3
	9 13 1.2E5 1.0E4
	10 14 1.2E5 1.0E4
	13 14 2.0E6 1.8E5
	15 16 2.0E6 1.8E5
	17 18 2.0E6 1.8E5
	12 13 14

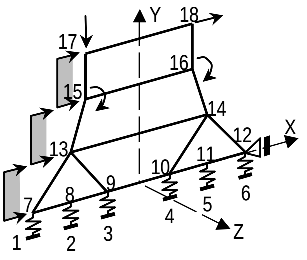


Table 9. Format of data files for space trusses

Space trusses (files CST*.TXT and DST*.TXT):	
General	**Example**
Project	Space truss – Figure 11e
Fu Lu n m	kN m 15 39
free line	
T_1 X_1 Y_1 Z_1 [F_{X1} F_{Y1} F_{Z1}]	8 0.0 -2.0 0.0 0 0 -40
T_2 X_2 Y_2 Z_2 [F_{X2} F_{Y2} F_{Z2}]	8 0.0 2.0 0.0 0 0 -120
……	1 0.0 0.0 5.0 50
	1 4.0 -2.0 0.0 0 0 -80
	1 4.0 2.0 0.0
	1 4.0 0.0 5.0 0 -30

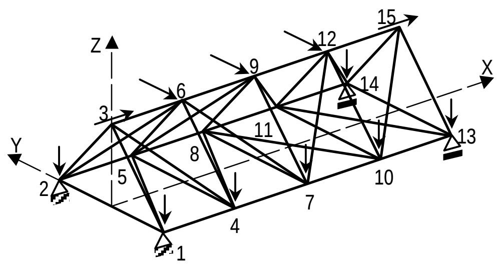
Continued on the next page…

Table 9 continued:

T_i Xi Yi Z_i $[F_{Xi}$ F_{Yi} $F_{Zi}]$
……
T_n X_n Y_n Z_n $[F_{Xn}$ F_{Xn} $F_{Zn}]$
	`1  8.0 -2.0  0.0  0   0  -80`
	`1  8.0  2.0  0.0`
	`1  8.0  0.0  5.0  0 -30`
	`1 12.0 -2.0  0.0  0   0  -80`
	`1 12.0  2.0  0.0`
	`1 12.0  0.0  5.0  0 -30`
	`8 16.0 -2.0  0.0  0   0  -40`
	`8 16.0  2.0  0.0  0   0 -120`
	`1 16.0  0.0  5.0 50`

free line	

b_1 e_1 EA_{x1}
b_2 e_2 EA_{x2}
……
b_j e_j EA_{xj}
……
b_m e_m EA_{xm}
	` 1  4  2.0E5`
	` 4  7  2.0E5`
	` 7 10  2.0E5`
	`10 13  2.0E5`
	` 2  5  2.0E5`
	` 5  8  2.0E5`
	` 8 11  2.0E5`
	`11 14  2.0E5`
	` 3  6  4.0E5`
	` 6  9  4.0E5`
	` 9 12  4.0E5`
	`12 15  4.0E5`
	` 1  2  1.0E6`
	` 4  5  1.0E6`
	` 7  8  1.0E6`
	`10 11  1.0E6`
	`13 14  1.0E6`
	` 1  3  5.0E4`
	` 2  3  5.0E4`
	` 4  6  5.0E4`
	` 5  6  5.0E4`
	` 7  9  5.0E4`
	` 8  9  5.0E4`
	`10 12  5.0E4`
	`11 12  5.0E4`
	`13 15  5.0E4`
	`14 15  5.0E4`
	` 3  4  1.0E5`
	` 2  6  1.0E5`
	` 6  7  1.0E5`
	` 5  9  1.0E5`
	` 7 12  1.0E5`
	` 9 11  1.0E5`
	`10 15  1.0E5`
	`12 14  1.0E5`
	` 1  5  1.0E5`
	` 4  8  1.0E5`
	` 8 10  1.0E5`
	`11 13  1.0E5`



Regarding the input of real values, please observe the following:

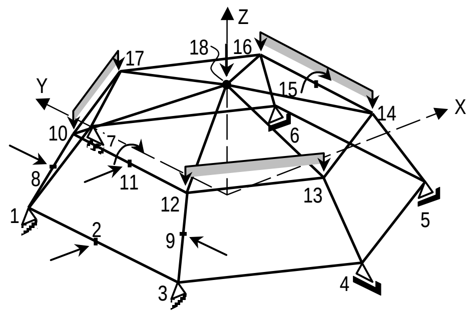
- The Anglo-Saxon notation should be used, i.e. with decimal points and not decimal commas.
- If you use a decimal point, DISCO expects at least one digit behind it. For the notations like ‘10.’, an error message will be returned.
- You can choose between the decimal (e.g. 9.81) and exponential (e.g. 0.981E1) notation by each individual data. Both positive and negative exponents are acceptable.
- As the output will be returned in a decimal notation, it is advisable to choose such force and length units that the results will form very long numbers. E.g. for a bridge, it is better to input in the data kiloNewtons (kN) and meters (m) than in Newtons (N) and millimeters.

Table 10. Format of data files for space frames

Space frames (files CSF*.TXT and DSF*.TXT):

General

Project
Fu Lu n m
free line
T_1 X_1 Y_1 Z_1 [F_{X1} F_{Y1} F_{Z1} M_{X1} M_{Y1} M_{Z1}]
T_2 X_2 Y_2 Z_2 [F_{X2} F_{Y2} F_{Z2} M_{X2} M_{Y2} M_{Z2}]
……
T_i X_i Y_i Z_i [F_{Xi} F_{Yi} F_{Zi} M_{Xi} M_{Yi} M_{Zi}]
……
T_n X_n Y_n Z_n [F_{Xn} F_{Xn} F_{Zn} M_{Xn} M_{Yn} M_{Zn}]
free line
b_1 e_1 EA_{x1} GI_{x1} EI_{y1} EI_{z1} [q_{X1} q_{Y1} q_{Z1}]
b_2 e_2 EA_{x2} GI_{x2} EI_{y2} EI_{z2} [q_{X2} q_{Y2} q_{Z2}]
……
b_j e_j EA_{xj} GI_{xj} EI_{yj} EI_{zj} [q_{Xj} q_{Yj} q_{Yj}]
……
b_m e_m EA_{xm} GI_{xm} EI_{ym} EI_{zm} [q_{Xm} q_{Ym} q_{Zm}]
free line
[j_1 j_2 j_3 j_4 …]



Example

```
Space frame - Figure 11f
kN m 18 29

57 -5.0  2.9  0.0
 1 -5.0  0.0  0.0  100
57 -5.0 -2.9  0.0
25  0.0 -5.8  0.0
41  5.0 -2.9  0.0
41  5.0  2.9  0.0
57  0.0  5.8  0.0
 1 -4.5  2.6  2.0    0 -50
 1 -4.5 -2.6  2.0    0  80
 1 -4.0  2.3  4.0
 1 -4.0  0.0  4.0  150   0   0 120
 1 -4.0 -2.3  4.0
 1  0.0 -4.6  4.0
 1  4.0 -2.3  4.0
 1  4.0  0.0  4.0    0   0   0 120
 1  4.0  2.3  4.0
 1  0.0  4.6  4.0
 1  0.0  0.0  5.5    0   0 -60

 1  2 1E5 5E3 2E4 2E4
 2  3 1E5 5E3 2E4 2E4
 3  4 1E5 5E3 2E4 2E4
 4  5 1E5 5E3 2E4 2E4
 5  6 1E5 5E3 2E4 2E4
 6  7 1E5 5E3 2E4 2E4
 7  1 1E5 5E3 2E4 2E4
 1  8 5E4 2E3 8E3 8E3
 8 10 5E4 2E3 8E3 8E3
 3  9 5E4 2E3 8E3 8E3
 9 12 5E4 2E3 8E3 8E3
 4 13 5E4 2E3 8E3 8E3
 5 14 5E4 2E3 8E3 8E3
 6 16 5E4 2E3 8E3 8E3
 7 17 5E4 2E3 8E3 8E3
10 11 1E5 5E3 2E4 2E4
11 12 1E5 5E3 2E4 2E4
12 13 1E5 5E3 2E4 2E4   0   0 -20
13 14 1E5 5E3 2E4 2E4
14 15 1E5 5E3 2E4 2E4   0   0 -20
15 16 1E5 5E3 2E4 2E4   0   0 -20
16 17 1E5 5E3 2E4 2E4
17 10 1E5 5E3 2E4 2E4   0   0 -20

10 18 5E4 2E3 8E3 8E3
12 18 5E4 2E3 8E3 8E3
13 18 5E4 2E3 8E3 8E3
14 18 5E4 2E3 8E3 8E3
16 18 5E4 2E3 8E3 8E3
17 18 5E4 2E3 8E3 8E3

16 17 18 19 20 21 22 23 24 25
```

11.2. Input in a DISCO dialogue

DISCO offers also an opportunity to input the data interactively, in a dialogue with the user. This option requires some more key strokes, but it may still be convenient due to the built-in data control subroutines which will not let any incorrect value pass through. The dialogue begins already on the program opening screen, which looks like this:

```
 Gdansk Institute of Technology - Faculty of Hydro & Environmental Engineering
------------------------------------------------------------------------------
|                                  D I S C O                                 |
| ANALYSIS OF STRUCTURES WITH CONTINUOUS AND DISCONTINUOUS SUPPORT CONDITIONS |
------------------------------------------------------------------------------
R.A. Daniel                                                      Version 4/04


DISCO computes the following types of structures:

Continuously supported:                          Discontinuously supported:

 1   Continuous beam                               2   Discontinuous beam
 3   Continuous plane truss                        4   Discontinuous plane truss
 5   Continuous grid                               6   Discontinuous grid
 7   Continuous plane frame                        8   Discontinuous plane frame
 9   Continuous space truss                       10   Discontinuous space truss
11   Continuous space frame                       12   Discontinuous space frame

Your choice (0= Exit) : _
```

Make sure that the DISCO data diskette is in drive A:\ at this moment. You may now enter the type of structure which you want to analyze. Let us assume that it is a continuous plane frame. Type **7** and press [Enter]. The program response will be about as follows:

```
Available data files of this type:

 1   Cpf1.txt: Cont. plane frame, EX1       2   Cpf2.txt: Cont. plane frame, EX2
 3   Cpf3.txt: Small offshore rig           4   Cpf4.txt: Hartelkering, stijlen
 5   Cpf5.txt: Frame – Figure 11d           6   Cpf6.txt: Free

Your choice (0= Exit) : _
```

If you want to process (*Delete*, *Update*, *Append*, *Model*, *Output* or *Setup* for computing) an existing data file, you will enter its number (in this case **1**..**5**). Take care not to do it when you intend to *Input* a new file, as it will overwrite the existing one. We now discuss an entirely new input, therefore type **6** and press [Enter]. DISCO will then open a free file **Cpf6.txt** with only one processing option - *Input*:

```
Available processing options:

 1   Input

Your choice (0= Exit) : _
```

Typing **1** and pressing [Enter] opens then the input dialogue, in which DISCO asks the succeeding data about your structure; and you enter those data from the keyboard. If the entry is incorrect, the program will not accept it, otherwise it will display it and ask you to confirm it by prompting ‘(**Y**/**N**)?’ behind. You can change it then by pressing **N** or go to the next data by pressing **Y**. For the plane frame from Fig. 11d, the screen will look as follows after the general data has been input:

```
Input     F1= Repeat    F2= Finish    Esc= Escape    Other= Go on     Cpf6.txt
------------------------------------------------------------------------------
                  General data:

Project        :   Plane frame – Figure 11d
Force units    :   kN
Length units   :   m
No. of joints  :   18
No. of members :   22_
```

Four options will appear in the top line:

- **F1** makes the program go back to the entry ‘Project’ and repeat this part of the dialogue;
- **F2** allows you to save the completed part of the input and go back to the previous screen, which will now show 3 processing options: *Delete*, *Update* and *Append*. You can then press **0** to take a break or use *Append* to resume your work,.
- **Esc** will erase all new input. If you are in the *Input* mode, it will erase the new opened file. If you are in the *Append* or *Update* mode, it will only erase all additions or updates.
- Any **other** key will continue the *Input* dialogue.

Press, indeed, any **other** key which will bring you to the second part: the input of joint data. DISCO will now ask the joint type, joint coordinates and joint concentrated loads for all succeeding joints, checking every entry and asking you to confirm it. At the end of the first joint input, the screen will look like this:

```
Input     F1= Repeat    F2= Finish    Esc= Escape    Other= Go on     Cpf6.txt
------------------------------------------------------------------------------
                  Joint data:

Joint   1 :       t =     4          X =    -6.000       Y =    -0.200
                  FX=     0.000      FY=     0.000       MZ=     0.000
```

The same four options appear now in the top line. Pressing **F1** repeats the dialogue about this particular joint; other options work as discussed above. Press any **other** key to go to joint 2, then joint 3 etc. When all joint data has been input and you have not taken a break by pressing **F2**, DISCO will go to the third part of the *Input* dialogue: the member data. You will now be asked to input in succession: the member beginning and end joint, the axial rigidity EA_x, the flexural rigidity EI_z and the member distributed loads. At the end of the first member input, the screen will look like this:

```
Input     F1= Repeat    F2= Finish    Esc= Escape    Other= Go on     Cpf6.txt
------------------------------------------------------------------------------
                  Member data:

Member   1 :      from         1    to
                  7                    EIz=     1.000
                  EAx=   2000.000      QY=      0.000
                  QX =      0.000
```

The keys **F1**, **F2**, **Esc** and any **other** allow again for, respectively, repeating the member data input, breaking the job, erasing the entire new input and continuing the dialogue. Press any **other** key to go to member 2, then member 3 etc. When all member data has been input and you have not taken a break by pressing **F2**, DISCO will go to the fourth and last part of the *Input* dialogue: the members for extended output. You will be asked to enter the numbers of members for which you like to receive the locations and values of extreme deflections and/or bending moments. Entering those members proceeds in a dialogue similar to what has already been discussed – and is terminated by entering **0**. When this is successfully completed, the following screen should appear:

```
Input complete                                                    Cpf6.txt
--------------------------------------------------------------------------
Your data file : Cpf6.txt

Available processing options:

 1 Input     2 Delete    3 Update    4 Append    5 Model     6 Output    7 Setup

Your choice (0= Exit) : _
```

If there are less (e.g. only the first four) processing options at the end of your input, it means that some incorrect data has been entered, not detected by the DISCO verifying routines. The program will usually help you localize it, by issuing a message like “Bad joint 15” or “Bad member 20”. Use e.g. *Update* to correct it. The use of a *.txt file editor – discussed in section 11.2 – is less convenient, because DISCO stores all real values in an exponential notation, 11 digits long, which is as not easy to survey as the decimal notation. For this reason, it is also better not to let it replace the data prepared using a text editor, unless really necessary.

Having successfully completed the input, you can now view the structure model using the option *Model*. It gives a simple graphical presentation of the structure model – meant only for screen control, not for printing. Using the option *Output* will produce another data file, called ‘LastDat.txt’, decently arranged in tables and suitable for a hard print. This data file will be stored in the directory C:\DANCE.

The option *Setup* computes some memory constants and performs a simple band matrix optimization, especially useful for large models which might otherwise cause a memory overflow. This optimization is an original DISCO routine. Simply speaking, it divides the band matrix into a number of dynamic submatrices, most of which are narrower than the band matrix width. This saves the memory allowing to compute more complex models. After performing Setup, the problem is ready for actual computation, which is announced in the following manner:

```
- Computing memory constants
- Rock & Roll optimization
- Setting up for processing

DISCO set up for : Plane frame – Figure 11d
Joints        18
Members       22
- matrix  1  from   1  to  18,   band width  5

Run DANCE

Strike any key _
```

12. PROGRAM OPERATION

The program operation starts by choosing the structure type and submitting the input data, as discussed in chapter 11. Whether the input has been prepared using a text file editor or the DISCO dialogue, you still need to get a screen showing the seven processing options (see preceding page), run the option *Setup* and get the screen telling you to run DANCE. Pressing a key closes DISCO and brings you back to the operating system. In order to perform the actual computing, you can now do the following:

- under MS Windows: double-click on the icon DANCE;
- under MS DOS: make sure you have the prompt C:\DISCO\, type DANCE and press [Enter][17].

DISCO will now compute the problem in a single run (for continuous structures) or an iteration process described in chapters 4 and 6 (for discontinuous structures). There will be a "cloud" of numbers flying" through your screen, impossible to follow due to the high speed. Do not pay attention to that. These numbers represent the band matrix structure at different steps of the Gaussian elimination and the iteration process. They had been helpful during the programming, when PC's worked much slower than now, but they became incommunicative later. The only reason to display them now is that they may still be helpful in case of program modifications or extensions in the future. At the end of this computing, DISCO finds the solution in terms of a displacement matrix of all joints; and stores it in on drive A:\ in a temporary file Temp.txt. You should then receive the following message:

```
MODEL SOLVED

Setting up for output: Cpf6.txt
DISCO ready to output: Cpf6.txt

Run DANCE

Strike any key _
```

The user is asked to run DANCE again – but do not be confused, it is not the same DANCE as the one in section 11.2. In order to understand what happened, you should take a look at the global program layout shown in Fig. 15. DISCO consists actually of three main blocks, which should be run in succession and which do not communicate with each other during operation. These blocks are:

- Input block;
- Processing block;
- Output block.

Moreover, these blocks do not even exist together at the same time. The truth is that the first block writes the second; and the second one writes the third – after erasing itself from your computer hard disk. This makes it possible that the block two and three have the same names: DANCE. But still more important is the fact that the second, processing block is in this way freed of all the tasks that can be separated from solving the simultaneous equation system. Solving that system is the most memory consuming procedure in structural analysis programs.

As the program blocks erase and write themselves in every run, they can also "tailor" themselves to the type of structure that is being processed. This allows for still more efficiency in memory use. However, such a programming method requires that a new-generated program is compiled during the actual computing session. Therefore, a runtime compiler of Turbo Pascal 4.0, TPC.EXE, makes part of the program package, which has also been shown in Fig. 15.

[17] Obviously, you do not need to care about the prompt C:\DISCO if you add it to the PATH command in your AUTOEXEC.BAT file.

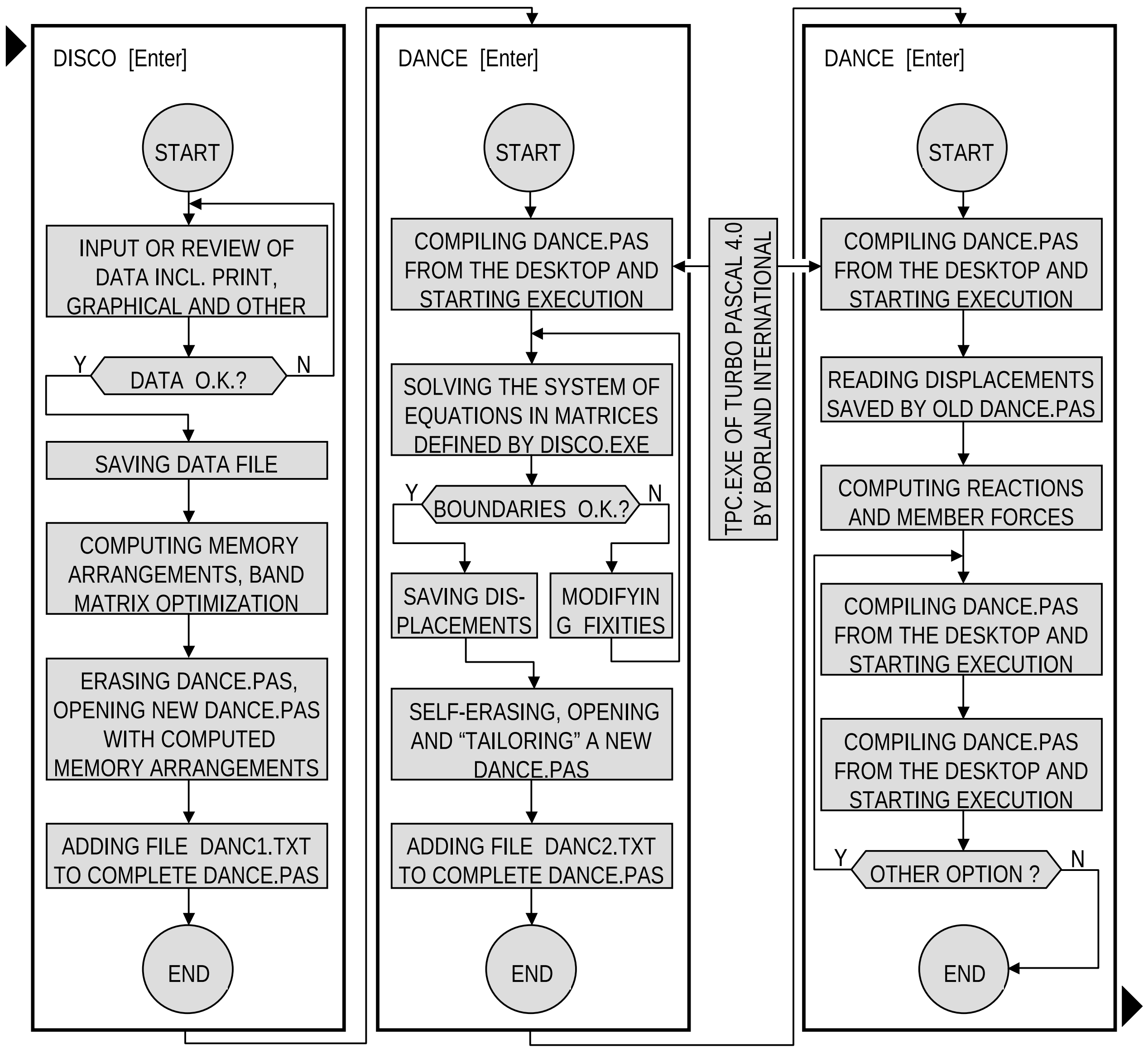

DISCO [Enter]
START
INPUT OR REVIEW OF DATA INCL. PRINT, GRAPHICAL AND OTHER
DATA O.K.?
Y
N
SAVING DATA FILE
COMPUTING MEMORY ARRANGEMENTS, BAND MATRIX OPTIMIZATION
ERASING DANCE.PAS, OPENING NEW DANCE.PAS WITH COMPUTED MEMORY ARRANGEMENTS
ADDING FILE DANC1.TXT TO COMPLETE DANCE.PAS
END
DANCE [Enter]
START
COMPILING DANCE.PAS FROM THE DESKTOP AND STARTING EXECUTION
SOLVING THE SYSTEM OF EQUATIONS IN MATRICES DEFINED BY DISCO.EXE
BOUNDARIES O.K.?
Y
N
SAVING DIS-PLACEMENTS
MODIFYIN G FIXITIES
SELF-ERASING, OPENING AND "TAILORING" A NEW DANCE.PAS
ADDING FILE DANC2.TXT TO COMPLETE DANCE.PAS
END
TPC.EXE OF TURBO PASCAL 4.0 BY BORLAND INTERNATIONAL
DANCE [Enter]
START
COMPILING DANCE.PAS FROM THE DESKTOP AND STARTING EXECUTION
READING DISPLACEMENTS SAVED BY OLD DANCE.PAS
COMPUTING REACTIONS AND MEMBER FORCES
COMPILING DANCE.PAS FROM THE DESKTOP AND STARTING EXECUTION
COMPILING DANCE.PAS FROM THE DESKTOP AND STARTING EXECUTION
OTHER OPTION ?
Y
N
END

Fig. 15. Three main program blocks of DISCO, from left to right: Input, Processing and Output

Let us go back to the last screen message. Pressing a key brings you back to the operating system. To receive and process the output, you should now do the same as before, i.e.:

- under MS Windows: double-click on the icon DANCE;
- under MS DOS: type DANCE on the prompt C:\DISCO\ and press [Enter].

The third block, Output, is activated now. DISCO reads the joint displacements from the file Temp.txt, computes the reactions and member internal loads ("member forces") and comes up with the message:

```
                                                  Output for Plane frame – Figure 11d
Choose output option:

  Complete       Partial       Selective      Graphical      Exit

Your choice: _
```

The output options are discussed in the following section.

13. OUTPUT OF SOLUTION

In order to save paper and spare the environment, DISCO allows you to view the solution first; and to present only the essential parts of it in the final output. Therefore, a number of output options have been programmed. Such additional facilities are possible thanks to the fact that the structure has already been computed and the large part of the computer memory has been freed. The first three of the output four main options shown in the last screen (one page back) can be delivered as screen output or as both the screen and the disk output. Here is that screen again after choosing, e.g., the complete output:

```
                                                     Output for Plane frame – Figure 11d
Choose output option:

  Complete      Partial       Selective     Graphical     Exit

Your choice: C

  Screen         Hard disk + Screen

Your choice: _
```

Below is a short description of the available output options.

Complete:

The complete output consists of the following parts:

- Program headlines and general data (see section 11.1);
- Displacements and rotations of all nodes (called “joints”);
- Support reactions (i.e. reactions in all externally fixed joints);
- Member internal loads (called “member forces”[18)]) at the beginning and the end of each member;
- Bending extremes (extreme deflections and moments) in all earlier specified members.

After choosing **C** for “Complete”, the computer will output these data in decent tables, easy to survey. Due to the problems with screen control under MS Windows by other than MS software, no data scroll routine has been programmed. If your output is long, you can better use the **H** option first and examine it in the hard disk file. There will still be an opportunity to shorten that file for the final presentation.

Partial:

This option gives you the opportunity to choose only those parts of the output that are of your particular interest. The format and the size of the output parts are the same as in the option “**C**omplete”, but you can skip the parts of less significance. The program will ask whether a part has to be output (displayed in **S**creen mode, or also put on the disk in **H**ard disk + Screen mode) before processing it. It is especially useful for quick or limited analyses, e.g. when only the system reactions are to be considered.

Selective:

The “**S**elective” output goes further than “**P**artial”, allowing you to tailor the output exactly to the form in which want to present it. The editing takes now place not only on the level of the output parts, but also on the level of particular joints and members. After printing each table headline, the program will ask you to enter – one by one – the joint or member numbers of your interest. Every entry is followed by

[18)] This term, less common in Europe, is largely used in America, e.g. in the classical MIT programs [11], [12].

immediate output for that joint or member. You may also enter them in your own succession or double the entries if you like. This option is especially useful for comparing and sorting purposes.

Graphical:

DISCO is not a graphically orientated program. Its graphical facilities serve only the purpose of a global control. Also in this case, the "**G**raphical" option will only prompt a view of the structure deformations, enlarged for a good survey. The user can chose between:

- Graphical view of only the deformed structure model;
- Graphical view of in the background undeformed, and in the foreground deformed model;

The deformed models are plotted using joint deformations only. The members connecting those joints are drawn as straight lines. You will, therefore, see polygonal lines instead of curves, which is an obvious simplification for all structure types except the trusses. The option "**G**raphical" gives only a screen presentation; no hard prints can be obtained.

Exit:

It is possible to run the ***Output*** block as many times and in as many options as one wishes. However, with the exception of "**G**raphical", you should take care that the final output version is the last which has been processed – anyhow the last which has been saved on the disk. Do not run ***Output*** (e.g. to "check one thing still") after you have completed the final version, because DISCO will overwrite it then. Press **E** for **E**xit after completing the output. This will end the session with the following message:

```
Your data output file: C:\DANCE\LastDat.txt
Your solution file:    C:\DANCE\LastSol.txt
Thank you.

Strike a key: _
```

Pressing any key brings you back to the operation system. You can now get the data file LastDat.txt and the solution file LastSol.txt from the hard disk using any word editor (e.g. WordPad – standard present by MS Windows); and make hard prints of those files. These prints are skipped in this manual for space reasons. There is, however, an input data file cpf5.txt on the attached diskette. You can run DISCO and process this file by yourself if you like to see the output.

14. SAMPLE PROBLEM: LEAKAGE OF A LOCK GATE

The complex system of water management in the Netherlands faces the designers with still higher demands. One of them is the construction of locks with mitre gates which can bear water pressure from both sides: the pointed, so-called *positive* side and the concave, so-called *negative* side. The second load case is unfavorable, as water tends then to open the gate instead of - as in the first case - keeping it closed. Despite leakage problems the idea wins still more support since it reduces the number of necessary mitre gate leaves.

The most recent project where this idea has been used, is the check gates of the double lock-aqueduct over a motorway, *Naviduct Enkhuizen*. This remarkable project gives a free navigation passage between two large lakes, *IJsselmeer* and *Markermeer*, which originate from the damming of the ancient Dutch internal see, *Zuiderzee*, in the early 1930's. The construction of this project was completed in 2003. The detailed design of the mitre gates was performed using the finite element analysis program DIANA [16], [17]. The contact- and the leakage problems of the gates were investigated using DISCO. Combining these two programs in one design proved to be successful in author's earlier hydrotechnical projects, e.g. the storm surge barrier on the Hartel Canal in the harbor of Rotterdam [18], [19].

Due to the symmetry, only one of leaf of the *Naviduct* mitre gate had to be modeled. Since the global geometrical behavior was of prior interest, not the local stresses, the computer model used by DISCO was highly simplified (Fig. 16). It was a 3D-frame model with the main body of the leaf in one plane. Only the drive arm lever and the line support to the other leaf did not lay in that plane. All elements were linear members; all internal joints were rigid, each with 6 DOF's.

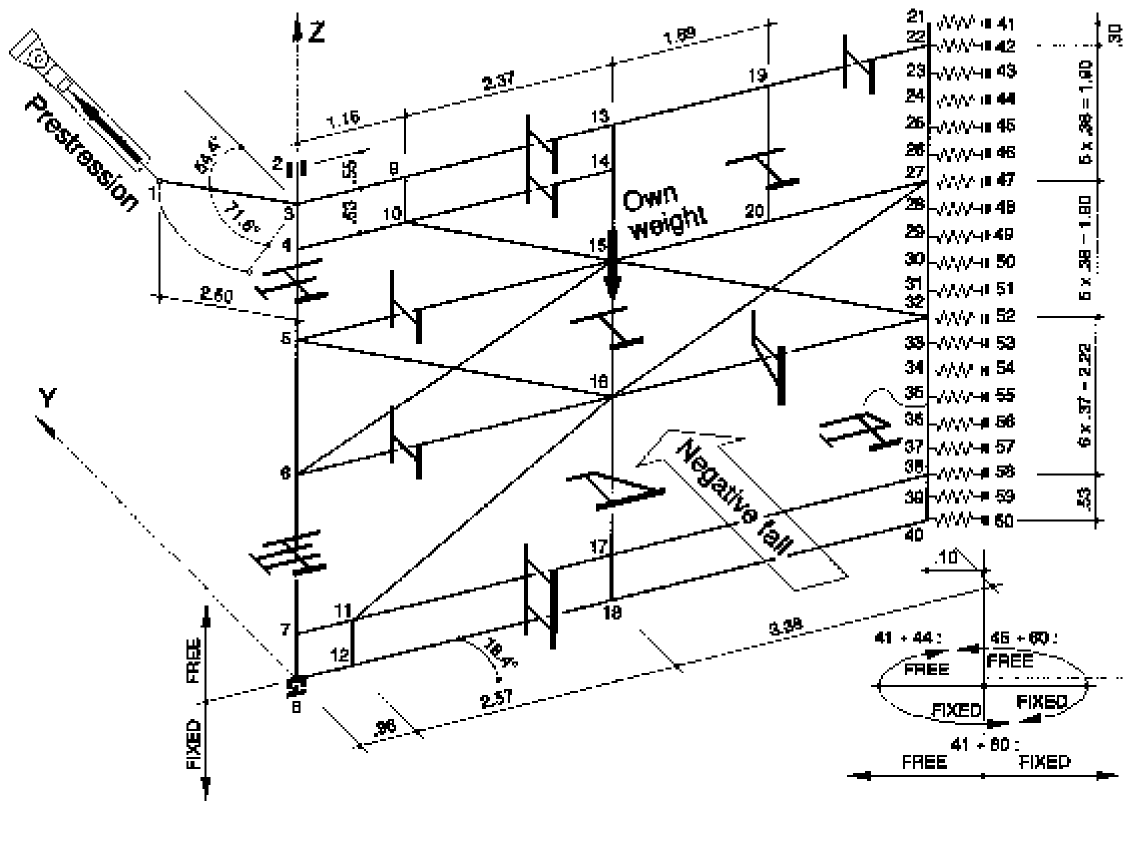


Fig. 16. Structural analysis model for one of the two gate leaves

When closed, the gate drive cylinders prestress the gate with a force $F_{y,1} \leq 1000$ kN in order to limit the opening which appears along the contact line under ***negative*** hydraulic load. This prestression results in a compression of the UHMPE[19] edge lining. The resultant of the hydraulic load acts some meters lower, tending to open the gate. Due to the complex torsional rigidity of the gate[20], it is impossible to determine the effective contact length directly as an input data. This problem has been solved using a row of conditional elastic supports which can only bear compression, see joints no. 41 through 60. When tension is computed, these joints become released to show the widths of a leakage gap between the two leaves. The gap between the bottom members and the threshold is computed simultaneously.

Table 11 presents some input excerpts for a negative water head (fall) of 1.0 m, which is a maximum for this lock operation. By larger falls (1.0 to 3.0 m) the navigation holds up, the negatively faced gate goes open and the opposite, positively faced gate bears the entire load. Yet, the negative fall of 1.0 m presents a more severe problem due to the leakage.

For demonstration reasons, some more types of discontinuous fixities have been modeled. The second one concerns the fixity of a rotation angle A_Z along the contact line. In the upper part, above water, the buffer is in fact twice as wide as underneath in order to sustain frequent prestression. When the whole gate deflects, the compressed contact line will have a fixed rotation about the Z-axis. Since the E-modulus of UHMPE is low (~300÷500 N/mm^2), this effect can practically be ignored, but let's assume that we like to see it in the stiffer upper part only. It can be done by fixing both sides of the rotation angle A_Z in that part. However, just for demonstration, single-sided rotation fixities have been used: The upper part (first 4 supports) is fixed against the positive A_Z rotation, which is expected to occur. The lower part (remaining 16 supports) is fixed against the negative A_Z rotation, which is not expected in this case. Finally, there is a single-sided fixity of a vertical displacement in a pivot bearing under the rotation axis (joint no. 8): downwards fixed, upwards free. A double-sided pinned support would be correct here as well since there is no doubt about the sign of the vertical support reaction. However, this is not always clear in more complex structures and/or load cases.

Table 11. Sample problem - input excerpts

```
Joint data:

Joint Type      X(m)       Y(m)       Z(m)   -DX+  -DY+  -DZ+  -AX+  -AY+  -AZ+

   1    1     -2.033      1.455      6.550   /  /  /  /  /  /  /  /  /  /  /  /
   2 3841      0.000      0.000      7.100   #  #  #  #  /  /  /  /  /  /  /  /
   3    1      0.000      0.000      6.550   /  /  /  /  /  /  /  /  /  /  /  /
. . . . . . . .
   7    1      0.000      0.000      0.530   /  /  /  /  /  /  /  /  /  /  /  /
   8 3969      0.000      0.000      0.000   #  #  #  #  #  /  /  /  /  /  /  /
   9    1      1.101      0.366      6.550   /  /  /  /  /  /  /  /  /  /  /  /
. . . . . . . .
  41 1026      6.657      2.181      6.850   /  #  /  /  /  /  /  /  /  /  #  #
  42 1026      6.657      2.181      6.550   /  #  /  /  /  /  /  /  /  /  #  #
  43 1026      6.657      2.181      6.170   /  #  /  /  /  /  /  /  /  /  #  #
  44 1026      6.657      2.181      5.790   /  #  /  /  /  /  /  /  /  /  #  #
  45 1027      6.657      2.181      5.410   /  #  /  /  /  /  /  /  /  /  /  /
  46 1027      6.657      2.181      5.030   /  #  /  /  /  /  /  /  /  /  /  /
. . . . . . . .
  58 1027      6.657      2.181      0.530   /  #  /  /  /  /  /  /  /  /  /  /
  59 1027      6.657      2.181      0.265   /  #  /  /  /  /  /  /  /  /  /  /
  60 1027      6.657      2.181      0.000   /  #  /  /  /  /  /  /  /  /  /  /
```

[19] **U**ltra **H**igh **M**olecular **P**oly**e**thylene.

[20] The torsional rigidity is built up by diagonals between beam rear flanges. In a plane model this can be simulated e.g. using the approach presented by Kollbrunner [20] or Dąbrowski [21].

```
Member data:

Member From To         EAx(kN)       GIx(kNm²)        EIy(kNm²)        EIz(kNm²)

   1     1   3    10710000.000        2536.000        43200.000       738600.000
   2     2   3    10550000.000      158000.000     21000000.000       222200.000
. . . . . . .
  29     9  13     7346000.000         564.800     21000000.000       417900.000
  30    10  14     7346000.000       56070.000     21000000.000       417900.000
  31    13  19     7346000.000         564.800     21000000.000       417900.000
  32    19  22     7346000.000         564.800     21000000.000       417900.000
  33     5  15     7480000.000      157700.000     21000000.000       249100.000
  34    15  20     7480000.000      111100.000     21000000.000       249100.000
. . . . . . .
  58    21  41       25100.000         100.000         1000.000          101.100
  59    22  42       25100.000         100.000         1000.000          101.100
  60    23  43       25100.000         100.000         1000.000          101.100
  61    24  44       25100.000         100.000         1000.000          101.100
  62    25  45       13700.000         100.000         1000.000           16.400
  63    26  46       13700.000         100.000         1000.000           16.400
  64    27  47       13700.000         100.000         1000.000           16.400
  65    28  48       13700.000         100.000         1000.000           16.400
  66    29  49       13700.000         100.000         1000.000           16.400
  67    30  50       13700.000         100.000         1000.000           16.400
  68    31  51       13700.000         100.000         1000.000           16.400
  69    32  52       13700.000         100.000         1000.000           16.400
  70    33  53       13300.000         100.000         1000.000           15.900
  71    34  54       13300.000         100.000         1000.000           15.900
  72    35  55       13300.000         100.000         1000.000           15.900
  73    36  56       13300.000         100.000         1000.000           15.900
  74    37  57       13300.000         100.000         1000.000           15.900
  75    38  58       11500.000         100.000         1000.000           13.700
  76    39  59        9500.000         100.000         1000.000           11.500
  77    40  60       18000.000         100.000         1000.000           21.600

Joint loadings:

Joint  Type     FX(kN)     FY(kN)     FZ(kN)     MX(kNm)     MY(kNm)     MZ(kNm)

  1      1      0.000   1000.000      0.000       0.000       0.000       0.000
 15      1      0.000      0.000   -220.000       0.000       0.000       0.000

Member loadings:

Member From To     QX(kN)     QY(kN)     QZ(kN)

  33     5  15    -10.590     31.830      0.000
  34    15  20     -5.280     15.870      0.000
  35    20  27     -5.280     15.870      0.000
  36     6  16    -22.950     69.000      0.000
  37    16  32    -22.950     69.000      0.000
  38     7  11     -4.180     12.570      0.000
  39     8  12     -1.090      3.280      0.000
  40    11  17    -10.880     32.710      0.000
  41    12  18     -2.920      8.780      0.000
  42    17  38    -15.380     46.220      0.000
  43    18  40     -4.010     12.060      0.000

Members for extended output:  42  43
```

DISCO needs 5 iteration steps to solve this sample problem. The computation time on a 133 MHz Intel Pentium® PC is about 120 sec. This time was measured in the late 1990's. There has been much progress in microprocessor speeds since then, therefore only a fraction of this time will be required today. The performances of this range are typical for problems of medium until high complexity, which may be considered the case here due to the 41 discontinuous fixities. The solution is numerically stable, there are e.g. no visible inaccuracies or traceable differences between the totals of loads and reactions. The output excerpts interesting for this manual are presented in table 12.

Table 12. Sample problem - output excerpts

```
Joint displacements:

Joint Type   DX(m/1e3)   DY(m/1e3)   DZ(m/1e3)    AX(1e-3)   AY(1e-3)   AZ(1e-3)

   1     1      9.4280     14.3150      1.4698      0.9172     0.1801    -7.7712
   2  3841      0.0000      0.0000     -0.2309      1.6380     0.1823    -4.3305
   3     1     -0.0999      0.7688     -0.2309      0.9172     0.1801    -4.3305
. . . . . . .
   7     1     -0.0633      0.2379     -0.0086     -0.4589    -0.1197     2.6146
   8  3969      0.0000      0.0000      0.0000     -0.4580    -0.1189     3.2261
   9     1      1.0912     -2.8855     -0.1288      1.3718     0.3910    -2.5717
. . . . . . .
  41  1026      0.0000     -2.5662     -0.1144      3.1876     1.0380     0.0000
  42  1026      0.0000     -1.6082     -0.1144      3.1876     1.0385     0.0000
  43  1026      0.0000     -0.3871     -0.1164      3.2421     1.0375     0.0000
  44  1026     -0.2303      0.8526     -0.1183      3.2739     1.0374     0.0000
  45  1027     -0.6247      2.1921     -0.1204      3.2828     1.0383     1.7983
  46  1027     -1.0196      3.4440     -0.1226      3.2690     1.0402     1.8612
  47  1027     -1.4154      4.6863     -0.1249      3.2323     1.0431     1.9242
  48  1027     -1.8118      5.9244     -0.1307      3.2659     1.0437     1.9538
  49  1027     -2.2086      7.1722     -0.1364      3.2831     1.0443     1.9833
  50  1027     -2.6055      8.4234     -0.1422      3.2841     1.0450     2.0128
  51  1027     -3.0027      9.6719     -0.1479      3.2688     1.0457     2.0424
  52  1027     -3.4002     10.9115     -0.1537      3.2372     1.0464     2.0719
  53  1027     -3.7960     12.1157     -0.1593      3.2371     1.0904     2.1346
  54  1027     -4.2051     13.3188     -0.1632      3.2316     1.1183     2.1972
  55  1027     -4.6216     14.5189     -0.1656      3.2205     1.1302     2.2598
  56  1027     -5.0395     15.7138     -0.1663      3.2038     1.1260     2.3224
  57  1027     -5.4528     16.9015     -0.1654      3.1816     1.1057     2.3851
  58  1027     -5.8557     18.0800     -0.1630      3.1538     1.0695     2.4477
  59  1027     -6.1391     18.9171     -0.1644      3.1391     1.0692     2.4804
  60  1027     -6.4224     19.7504     -0.1638      3.1256     1.0688     2.5132

Support reactions:

Joint Type      RX(kN)      RY(kN)      RZ(kN)     MX(kNm)    MY(kNm)    MZ(kNm)

   2  3841    305.7436  -1058.9745      0.0000      0.0000    -0.0000     0.0000
   8  3969    199.3141   -258.2148    220.0000      0.0000    -0.0000     0.0000
  41  1026   -218.3036     -0.0000     -0.0000     -0.0000     0.0000    -1.7271
  42  1026   -140.1272     -0.0000      0.0000     -0.0000     0.0000    -1.7623
  43  1026    -41.1275      0.0000     -0.0000     -0.0000    -0.0000    -1.7359
  44  1026      0.0000     -0.0000      0.0000     -0.0000     0.0000    -1.7544
  45  1027      0.0000     -0.0000      0.0000     -0.0000    -0.0000     0.0000
  46  1027      0.0000     -0.0000      0.0000     -0.0000    -0.0000     0.0000
. . . . . . .
  59  1027      0.0000     -0.0000      0.0000     -0.0000    -0.0000     0.0000
  60  1027      0.0000     -0.0000      0.0000      0.0000    -0.0000     0.0000
```

Observe that only the first 3 elastic supports (joints 41, 42, 43) remain in contact with the gate other leaf. These joints undergo no displacements in the X-direction, and bear compressive reactions varying from 218 to 41 kN. In fact, this distribution of compression has been used in dimensioning the UHMPE front post lining. Below that part, a gap begins to open reaching 6.4 mm (twice due to the symmetry) in the bottom joint no. 60. The leakage gap along the threshold is a geometrical sum of displacements D_X and D_Y and reaches 20.8 mm in joint no. 60. These values have been used in designing additional soft gaskets to prevent excessive leakage.

As foreseen, the discontinuous fixities of the rotation angle A_Z along the contact line gave in its upper part some small reaction moments M_Z and no rotations. Below that part free positive rotations and no moments M_Z were computed. Discontinuous fixity of the D_Z displacement in the pivot bearing resulted in no displacement and an upward reaction R_Z. That reaction is exactly equal to the own weight of the gate reduced by the buoyancy, as input in joint 15 – which is one of the signs that a numerically stable solution has been computed.

The last part of the output covers the bending extremes for the members of the users particular interest. Bending extremes are the extreme bending moments and deflections in the member local coordinate system (see section 10.2). In this case the user was particularly interested in two members: no. 42 and 43. Below are the bending extremes computed for those members (Table 13). For the member 42, the entire lines of bending moments and deflections have also been computed. This facility is only available in the **S**elective output mode, in which DISCO will ask the user to specify the number of equal steps for such lines. Entering 0 skips this facility for the member in question.

Table 13. Sample problem - bending extremes

```
Bending extremes:

Member  42          x(m)      Mz(kNm)   Dy(m/1E3)      My(kNm)   Dz(m/1E3)

 Joint  17        0.0000      13.0012     10.1731      31.3101     -0.1260
 Mz extr.         1.3698      26.5221     13.7671       7.9211     -0.1171
 Dz extr.         0.5270      21.4035     11.5728      22.3119     -0.1377
 Dz extr.         3.1404       3.9309     18.1855     -22.3119     -0.0538
 Joint  38        3.3800      -2.5960     18.7718     -26.4025     -0.0560

   Step  0        0.0000      13.0012     10.1731      31.3101     -0.1260
   Step  1        0.4225      20.0556     11.2967      24.0961     -0.1372
   Step  2        0.8450      24.5375     12.4080      16.8820     -0.1342
   Step  3        1.2675      26.4467     13.5041       9.6679     -0.1213
   Step  4        1.6900      25.7833     14.5839       2.4538     -0.1026
   Step  5        2.1125      22.5474     15.6477      -4.7602     -0.0825
   Step  6        2.5350      16.7389     16.6977     -11.9743     -0.0652
   Step  7        2.9575       8.3578     17.7373     -19.1884     -0.0550
   Step  8        3.3800      -2.5960     18.7718     -26.4025     -0.0560

Member  43          x(m)      Mz(kNm)   Dy(m/1E3)      My(kNm)   Dz(m/1E3)

 Joint  18        0.0000      23.7466     11.4167      31.1117     -0.1271
 Mz extr.         2.1233      32.2229     17.2865      -6.3565     -0.0775
 Dz extr.         0.4711      27.0906     12.7582      22.7987     -0.1365
 Dz extr.         3.0551      30.5906     19.7075     -22.7987     -0.0527
 Joint  40        3.3800      29.2540     20.5295     -28.5315     -0.0570

                         0 = stop,  1..10 = jump
```

In the program, the extreme bending moments have been computed using analytical approach, which is in fact quite simple. The computation of extreme deflections is, however, not simple from the programming point of view. DISCO uses a modern iteration method here called ‘Illinois iteration’ [9], which is a modified, very fast version of a ‘classical’ *regula falsi*. A discussion on this matter goes, however, beyond the subject of the manual.

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